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Highway 17 / Kenora By-Pass Swedish Design Pavement Performance Report

MERO-038

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Abstract	In 1981, the Ministry of Transportation of Ontario (MTO) evaluated the Swedish pavement design method, conducting trial sections along Highway 17 / Kenora By-pass in Northwestern Ontario. Highway 17 / Kenora By-pass was the first and only highway built in Ontario using the Swedish design methodology. The Swedish design concept incorporates an open drainage layer in the pavement structure immediately below the asphalt pavement to improve drainage and thereby prolong pavement service life. Over the years, numerous performance reviews have been conducted to assess the appropriateness of the Swedish design in Ontario's environment. Detailed historical information and updated performance reviews are summarized and form the basis of this report.
Key Words	Highway 17, Kenora By-pass, Swedish Design, Pavement Performance Report, Open Drainage Stone, Hot In-place Recycling
Distribution	Unrestricted technical audience.

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Executive Summary

In 1981, the Ontario Ministry of Transportation (MTO) evaluated the Swedish pavement design method, conducting trial sections along Highway 17 / Kenora By-pass in Northwestern Ontario. This was the first and only highway built in Ontario using the Swedish design methodology.

Highway 17 / Kenora By-pass was divided into several sections during construction, which began in 1981, with the last contract built in 1989. The Swedish design concept incorporates an open drainage layer in the pavement structure immediately below the asphalt pavement to improve drainage; hence extending the pavement service life. However, there were constructability issues encountered when placing the Swedish design. Modifications to the Swedish design were made during construction to address the difficulties encountered.

Since its construction, the performance of the Kenora By-pass pavement sections has been assessed using various pavement evaluation methodologies and documented. This publication analyzed the design, construction and performance of the Swedish Design concept from 1988 through 2003, which forms the basis of this report. This publication also incorporates a new set of performance data collected between 2004 and 2009 following rehabilitation of the By-pass in 2003.

Introduction

Highway 17 / Kenora By-pass is a 34.5 km highway located in Northwestern Ontario. It was built from 1981 to 1989 using a modified Swedish design methodology. The By-pass was divided into eight sections for construction purposes and is comprised of different pavement structures. Detailed analysis and evaluation of the pavement performance for each pavement structure can be found in the following report.

PURPOSE

Highway 17 / Kenora By-pass was the first and only highway built in Ontario using the Swedish design methodology. The purpose of this report is to evaluate and document the performance of the Swedish design methodology used by the Ontario Ministry of Transportation (MTO).

APPROACH

Since its construction, the pavement condition of the Kenora By-pass has been assessed using both visual and automated pavement performance evaluation methodologies. The following chronology of performance evaluations was carried out on the original pavement sections:

1988	Performance Review of the Swedish Design versus Conventional Design
1999	Detailed Pavement Evaluation
2000	Automated Road Analyzer (ARAN) Performance Review
2001	Falling Weight Deflectometer (FWD) Evaluation
2002	Map Cracking Performance Review

In 2003, the entire By-pass was rehabilitated using Hot In-place Recycling (HIR). This was followed by a 50 mm Hot Mix Asphalt (HMA) overlay in 2007. The condition of the rehabilitated pavement was evaluated using the ARAN over five consecutive summers from 2004 through 2009.

The results of the pavement performance evaluations carried out since 1988 are presented in the subsequent sections of this publication together with analysis and recommendations on the use of the Swedish design method.

Swedish Design

INTRODUCTION OF SWEDISH DESIGN

Proper drainage is a crucial factor in pavement design and it has a direct influence on the pavement performance. A major contributing factor to pavement failure in the conventional pavement design method is the use of low permeability material for base material in the pavement structure. Water may be absorbed in the base instead of draining efficiently to the roadside ditches or drainage system, softening the road structure and may contribute to causing frost heaving.

The Swedish design pavement structure consists of crushed rock, decreasing in gradation from the subgrade to the asphalt surface course. Figure 1 shows a typical section of Swedish design pavement structure.

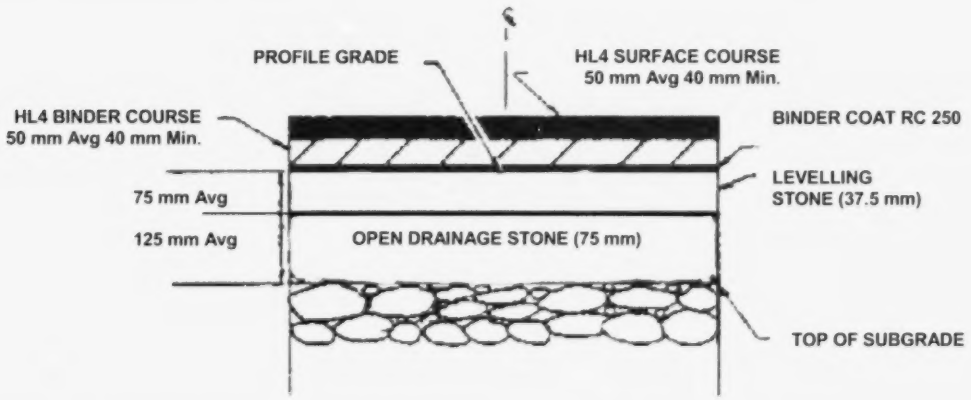

Figure 1 - Typical Section of Swedish Design Pavement Structure Constructed on Highway 17

Crushed rock at the bottom of the pavement structure, ranging in size from 8 to 75 mm is called the open drainage stone and its thickness is dependent on the subgrade material and traffic volume. The design gradation for the open drainage stone used for the Highway 17 By-pass is as follow:

Table 1 - Swedish Design Gradation for Open Drainage Stone

Sieve Size	% Passing
75 mm	100
37.5 mm	13 - 100
16 mm	3 - 50
9.5 mm	0 - 15
4.75 mm	0 - 5
75 um	0 - 2

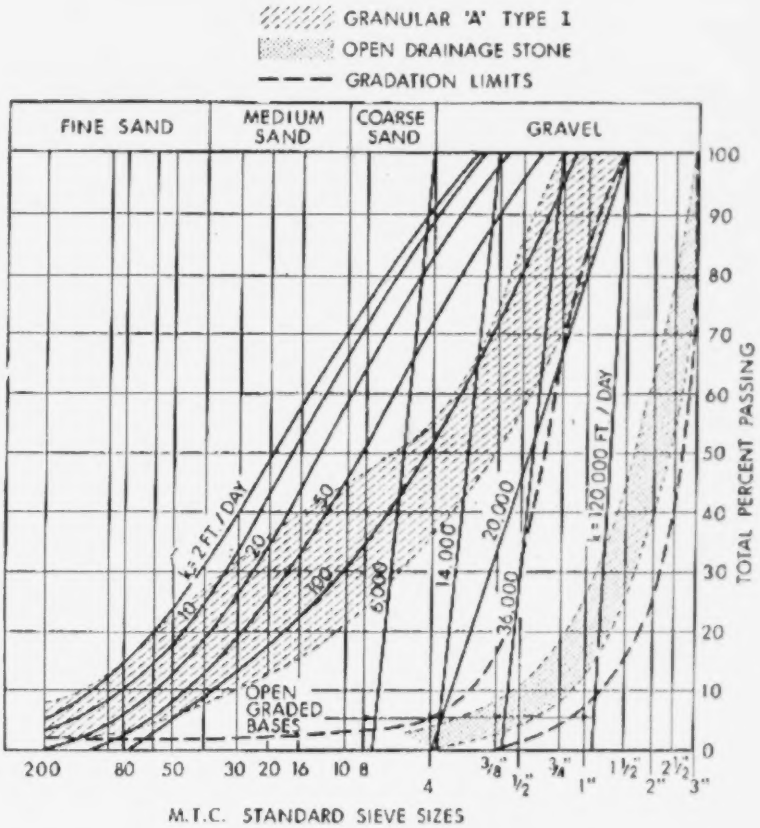

Figure 2 – Open Drainage Stone Gradation for Swedish Design Used in Kenora By-pass

Crushed rock ranging from 8 to 37.5 mm is screened off and used as levelling stone in the layer above the open drainage stone. The conventional Swedish design specifies a maximum allowable depth of 50 mm for levelling stone; however, the average depth of levelling stone constructed on Highway 17 was 75 mm due to constructability issues. The design gradation for the levelling stone layer used for the Highway 17 By-pass is as follows:

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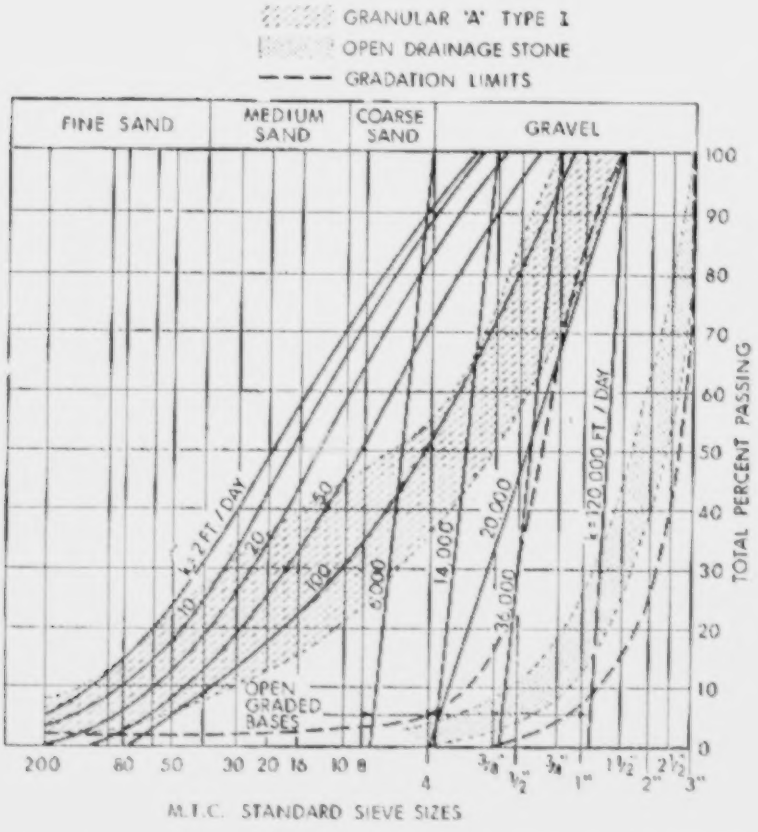

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Table 2 - Swedish Design Gradation for Levelling Stone Layer

Sieve Size	% Passing
37.5 mm	100
22.4 mm	40 - 100
16 mm	15 - 75
9.5 mm	0 - 15
4.75 mm	0 - 5
75 um	0 - 2

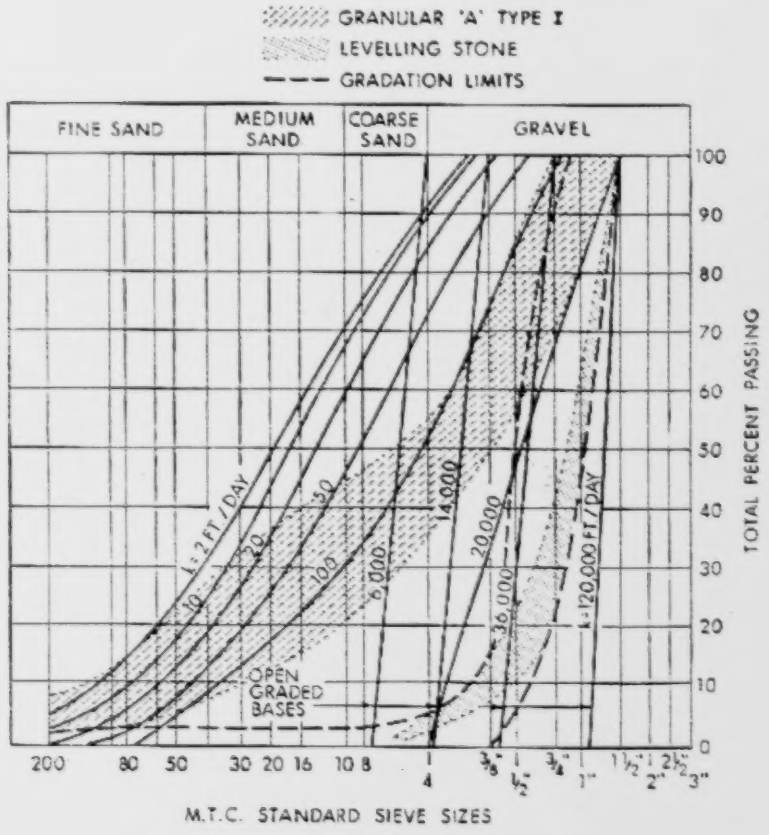

Figure 3 – Levelling Stone Gradation for Swedish Design Used in Kenora By-pass

As the pavement structure consists of only crushed rock, compaction is a very important element to the Swedish design. It was recommended that the open drainage stone be compacted with a vibratory roller, 5 passes or until all settlement has stopped. The levelling stone layer should be compacted with a minimum of 3 passes. To accommodate construction traffic, a thin surface treatment may be applied on top of the levelling stone to serve as a temporary wearing surface for traffic before placing hot mix asphalt.

Table 2 - Swedish Design Gradation for Levelling Stone Layer

Sieve Size	% Passing
37.5 mm	100
22.4 mm	40 - 100
16 mm	15 - 75
9.5 mm	0 - 15
4.75 mm	0 - 5
75 um	0 - 2

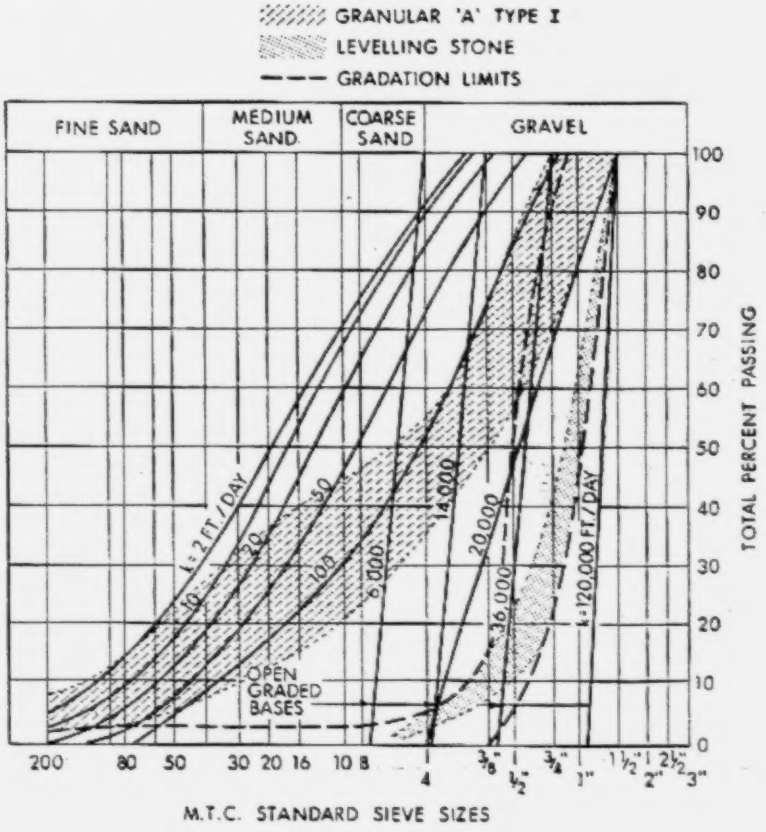

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Figure 4 below is a photo taken along the shoulder of Highway 17 / Kenora By-pass in 2002 showing the Swedish design with very coarse aggregate (75 mm) on the underlying layer, with a smaller sized aggregate levelling stone (37.5 mm) on the upper layer.

Figure 4 – Swedish Pavement Structure Design Looking From Shoulder

CONSTRUCTABILITY ISSUES ON SWEDISH DESIGN

The Ministry encountered construction difficulties when placing the Swedish design. In general, the Swedish design exhibited poor stability in both the open drainage stone layer and levelling stone layer even after proper compaction effort was made. This constituted a difficult paving situation for the paving equipment. It was suggested that more fines be included in the stone gradation to improve stability.

DIFFICULTIES ENCOUNTERED IN SWEDISH DESIGN PAVING CONTRACTS

The first paving contract on the Highway 17 / Kenora By-pass was performed under Contract 81-223, followed by the next paving Contract 87-227. The Swedish design pavement structure, consisting of two layers of crushed rock with a thin surface treatment, encountered some construction difficulties throughout.

It was found that the pavement structure was unstable. The open drainage stone and levelling stone base layers were continually moving under the asphalt layer, creating an unstable base layer for the pavement structure. The Swedish design did not provide a stable enough surface for the construction activities, and was not expected to have a superior performance for general traffic. More details on the construction Contracts 81-223 and 87-227 are provided in the following Historical Review section.

MODIFIED SWEDISH DESIGN

As a result of the Swedish design constructability issues on Contract 81-223 and 87-227 modification to the Swedish design was made to address the stability problems.

It was thought that the disadvantage of using two stone sizes in the Swedish design was once the surface treatment operation began, the base was disturbed, and the two materials mixed together. The smaller levelling stone migrated into the open drainage stone layer, leaving a very coarse material to cover with surface treatment.

On the next paving contract (Contract 88-206) all the stone was crushed to the smaller size (37.5 mm) to avoid the problems with loss of levelling stone into the open drainage stone layer. The contractor was required to place the stone in two layers using a spreader box. Also, the surface treatment binder was modified from HF 250 to RC-300 Prime for a quicker set up time, hence giving a more stable surface treatment. Figure 5 below shows a typical section of the modified Swedish design structure.

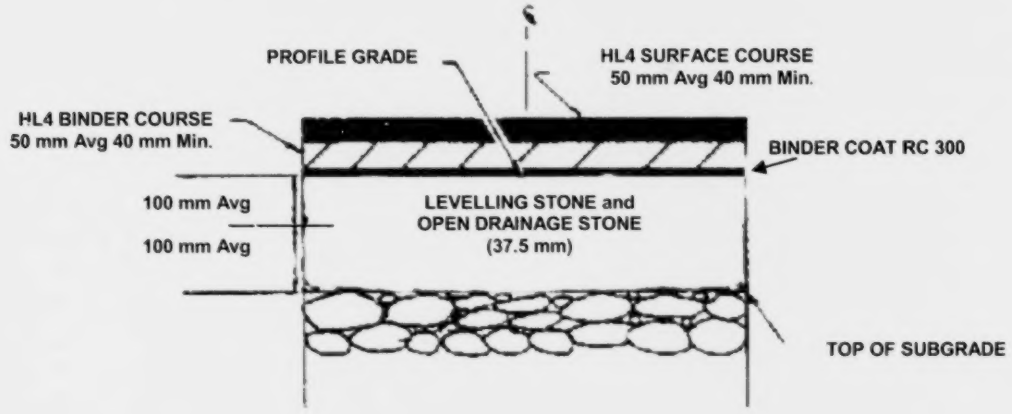

Figure 5 – Typical Section of Modified Swedish Design Pavement Structure

DIFFICULTIES ENCOUNTERED WITH THE MODIFIED SWEDISH DESIGN

Contract 88-206 was constructed using the modified Swedish design methodology which used the same 37.5 mm stone gradation for both levelling and open drainage stone. It was very difficult to work with due to the uniform gradation, and placing thick layers of the same gradation compromised the stability of the design. It was thought that the construction failure was caused by the inappropriate gradation of the modified design. These factors are likely the major cause of failure to this modified Swedish design. More details on the construction Contract 88-206 can be found in the following Historical Review section.

Therefore, the overall stability of this modified pavement structure was found to be less than the previous contracts using the conventional Swedish design methodology.

Historical Review

Highway 17 / Kenora By-pass was constructed under eight different contracts. Details of each contract are discussed in the following section of this report. Below are the Ministry paving and/or grading contracts involved in building the complete By-pass in ascending order:

- Contract 81-223 (Grading & Paving)
- Contract 83-221 (Grading)
- Contract 84-217 (Grading)
- Contract 86-204 (Grading)
- Contract 87-227 (Grading & Paving)
- Contract 88-206 (Grading & Paving)
- Contract 88-218 (Grading)
- Contract 89-213 (Grading and Paving)

HISTORICAL INFORMATION ON PREVIOUS CONTRACTS

The following Figure 6 indicates the location of these contracts along the By-pass.

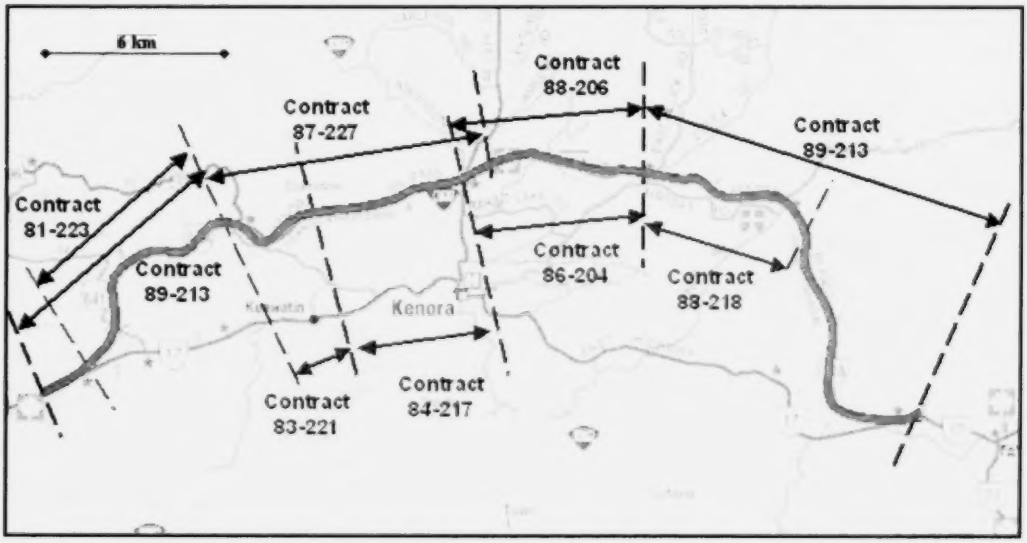

Figure 6 – Highway 17 / Kenora By-Pass with Historical Contracts

From Figure 6 above, the contract numbers appearing above the By-pass are grading and paving contracts; whereas the contract numbers appearing below are the grading only contracts.

The following Table 3 summarizes all the paving and/or grading contracts involved to complete this Highway 17 By-pass, including location and pavement design structure.

Table 3 – Historical Contract Records for Highway 17 / Kenora By-Pass

Contract & Location	Pavement Design	Pavement Structure
Contract 81-223 (WP 902-77-05) Hwy 17N from Hwy 17 easterly to Hwy 596 (6.7 km) *Overlaid in 1989 under Contract 89-213*	Swedish	40 mm HL4 sand seal (prime + screenings) 40 mm levelling stone (37.5 mm) 110 mm open drainage stone (75 mm)
Contract 83-221 (WP 902-77-15) Hwy 17 N from Hwy 596 easterly to Winnipeg River West Bridge (2.3 km)	Grading Only	Rock Grading
Contract 84-217 (WP 902-77-04) Hwy 17N from 2.8 km east of Hwy 596 (Winnipeg River West Bridge) easterly to Winnipeg River East Bridge / Hwy 666 (5.0 km)	Grading Only	Rock Grading
Contract 86-204 (WP 902-77-03) Hwy 17N from Hwy 666 easterly to Hwy 659 (6.1 km)	Grading Only	Rock Grading
Contract 87-227 (WP 902-77-13) Hwy 17N from 0.3 km west of Hwy 596 easterly to Hwy 659 (8.3 km)	Swedish	40 mm + 50 mm HL4 prime + screenings 75 mm levelling stone (37.5 mm) 125 mm open drainage stone (75 mm)
Contract 88-218 (WP 902-77-02, 22, 23) Hwy 17N from Hwy 659 easterly for 6.3 km, including 2 passing lanes	Grading Only	150 mm Granular A 150 mm Granular B, Type I
Contract 88-206 (WP 902-77-14) Hwy 658 easterly to Hwy 659 (6.1 km)	Modified Swedish	40 + 50 mm HL4 Surface Treatment 75 mm levelling stone (37.5 mm) 125 mm open drainage stone (37.5 mm)
Contract 89-213 (WP 902-77-01) Hwy 17N from 1.1 km west of west connection Hwy 17/17N easterly to Hwy 596 (8.5 km)	Swedish	40 mm + 40 mm HL4 prime + screening 40 mm levelling stone (37.5 mm) 110 mm open drainage stone (75 mm)
Contract 89-213 (WP 902-77-01) Hwy 17N from Hwy 659 easterly to 1.4 km east of east connection Hwy 17/17N (13.2 km) Includes 4.5 km OGDL test section from Hwy 17 westerly (11+600 to 16+100)	Conventional OGDL (4.5km)	40 mm + 40 mm HL4 150 mm Granular A 150 mm Granular B, Type I 100 mm OGDL (75 mm) 50 mm Granular A 150 mm Granular B, Type I

GRADING & PAVING CONTRACT 81-223

The initial Swedish pavement design for this contract consisted of two lifts of asphalt, over bituminous surface treatment using cutback or emulsion application to seal the surface over 50 mm of levelling stone and 200 to 1000 mm of open drainage stone. However, the contract drawing was modified and the following was the actual Swedish pavement design constructed for Contract 81-223:

- Surface course 40 mm HL4
- Prime coat (sand seal)
- 40 mm levelling stone
- 110 mm open drainage stone

The open drainage stone used for this contract was 100% passing 75 mm (75% crushed) stone, with 5% passing 4.75 mm. The compaction of this layer required five passes. The levelling stone used was 100% passing 37.5 mm (75% crushed) stone, with 5% passing 4.75 mm. The maximum allowable layer thickness was 50 mm, which required 3 compaction passes immediately following placement. The placement of the open drainage stone was carried out using end dumping and spreading with a dozer/grader, resulting in undulation in the final grade. The contractor had difficulty placing the open drainage stone, causing a very open surface which could not be readily paved over. The placement difficulties together with a variety of factors, including extensive swamp areas and a single lift of hot mix asphalt, resulted in a rolling ride over the finished grade. Furthermore, fine grading of the levelling stone could not correct the final grade of the pavement structure. Therefore, it was recommended in the final construction report that only one layer of crushed rock (40 to 50 mm size) be placed over the rock grade instead of using a two layer system.

There was a performance review conducted for this contract 81-223 in 1986, after 5 years of service. Following are the pavement deficiencies identified in the pavement performance evaluation at 5 years:

- Very slight distortion (roll in grade)
- Slight partial width transverse cracking throughout
- Slight full width transverse cracking, few, predominately in fills
- Slight centreline longitudinal cracking, few
- Slight longitudinal cracking along pavement edge and edge of shoulder

A crack count conducted along the By-pass between Highway 641 and Highway 596 indicated an average of 1 transverse crack every 35 metres. Overall, the performance of this Swedish design pavement section indicated poorer than normal conventional pavement performance considering a 200 Annual Average Daily Traffic (AADT) on this section of highway. However, the predominant distress was transverse cracking, which is due to thermal cracking and is not related to Swedish Design base course. Subsequently, this section was overlaid in 1989 under Contract 89-213 with 40 mm of HL-4.

Cost Comparison between Swedish and Conventional Design

The performance review generated a rough estimate for the construction cost using conventional pavement design versus the Swedish pavement design. It was found that the conventional cost was $71,000 for a 2-lane km highway; whereas the Swedish design cost was $139,000 for a 2-lane km highway. The cost difference was significant due to the availability of the granular material for conventional design from the Red Pine Pit located close to the project. The cost effectiveness of using Swedish design over conventional pavement design was in question.

GRADING CONTRACTS 83-221 AND 84-217

Contracts 83-221 and 84-217 were both grading-only contracts with paving to be done at a later date. The initial design was recommending the same Swedish design as per Contract 81-223 with minor modification be used for these two grading contracts. The initial design was 50 mm of levelling stone and 100 mm open drainage stone for Contract 83-221; whereas the design for Contract 84-217 was 50 mm levelling stone and 150 mm open drainage stone. It was also specified in the contract that a spreader box must be used to place 75 mm open drainage stone with a grade tolerance of ± 30 mm. However, Contracts 83-221 and 84-217 were revised to rock grading only, and the Swedish design base course grading was done in Contract 87-227.

GRADING & PAVING CONTRACT 87-227

There were many construction difficulties encountered for this paving Contract 87-227. The depths of the open drainage stone and levelling stone had been modified under grading Contract 84-217 due to the experience from Contract 81-223.

The original depths of open drainage stone and levelling stone were designed to be 100 mm and 50 mm respectively. The revised depths of open drainage stone were increased from 100 mm to 125 mm with 30 mm ± tolerance. The revised depths of levelling stone were from 50 mm to 75 mm depending on the open drainage stone elevation. Allowing for 10% of the open drainage stone loss into rock fill, and 50% of the levelling stone loss into open drainage stone layer, the final depth of the pavement structure would be 175 mm. There was a test section placed on Contract 87-227, between stations 18+192 to 18+469 where 175 mm of levelling stone was used to replace the typical Swedish design of 75 mm levelling stone and 125 mm open drainage stone for that section of pavement structure.

In this paving contract, it was impossible to work with the rubber-tired paving equipment even though the crushed stone was surface treated. A Cedar Rapids BSF-3 rubber-tired paver machine was used, but proved to be ineffective, as it continually broke through the surface treatment into the levelling stone. Ultimately, the contractor used a Cedar Rapids BSF-2 tracked paver machine to replace the rubber-tired paver to make this paving contract

feasible, but special attention was required throughout.

During construction, it was found that the pavement structure was unstable. The open drainage stone and levelling stone base was continually moving under the asphalt layer creating an unstable base layer for the pavement structure. The contractor produced the two stone gradation, 75 mm and 37.5 mm, with the 75 mm stone being extremely near the coarse side of the grading band. This led to a significant loss of the 37.5 mm stone into the open drainage stone. Fines were lost into the subgrade once the grade was disrupted by traffic, and additional vibration further migrated small particles from the surface, constituting a layer of the larger clear stone at the surface, resulted in wheel rutting and dishing.

In general, the Swedish design did not provide a stable enough surface for the construction activities. It was recommended to place a granular cap (binder and aggregate) over the levelling stone to provide stability and eliminate the surface treatment. It was also recommended to specify the use of a tracked paving machine in the next contract and to increase the percentage of fines in the levelling stone for better compaction.

GRADING & PAVING CONTRACT 88-206

Contract 88-206 was constructed using the modified Swedish design methodology to address the problems associated with using two stone sizes. This modified Swedish design consisted of the same stone gradation for both levelling and open drainage stone (37.5 mm maximum size) to avoid losing levelling stone into the open drainage stone layer. However, the overall stability of this modified pavement structure was observed to be less than the previous contracts using the typical Swedish design methodology.

The stability of the modified Swedish design was not acceptable, and the compaction of the HL-4 binder was low because it depressed into the levelling stone. It was found that the instability was caused by the inappropriate grading practise during the construction. The maximum grading thickness of an open drainage stone should be 1.5 to 2 times the largest stone size to ensure maximum stability. Thicker layers would cause excessive point-to-point contact between the larger stones, results in rolling of larger particles, which affect the overall stability of the pavement structure [1]. Furthermore, the typical Swedish design method is placed by end dumping and levelling with a grader instead of using a spreader box, as was carried out on Contract 88-206.

In general, the performance of the modified Swedish design did not have any major improvements over the ordinary Swedish design. Therefore, it was recommended to disregard this modification and continue to use two different stone sizes for levelling and open drainage stone layers for future contracts.

GRADING & PAVING CONTRACT 89-213

Contract 89-213 was a unique contract combined the finishing of the east end of the By-pass and the finishing of sections previously built under Contract 81-223. The east end of the contract is built using conventional design of 150 mm Granular A and 150 mm Granular B Type I with two lifts of hot mix; whereas the west end was remained as Swedish design and overlaid with 40 mm HL-4. The traffic was estimated to be 3.2 million Equivalent Single Axle Loads (ESALs) over 20 years, with 3000 AADT and 6000 Summer Average Daily Traffic (SADT).

There is an Open Graded Drainage Layer (OGDL) section at the east end of the By-pass with 100 mm OGDL, 50 mm Granular A and 150 mm Granular B Type I. OGDL is free drainage base material made up of 100% crushed HL-4 stone stabilized with 1.5% asphalt cement used to replace Granular A. The original design was to build the OGDL section for a length of 4.5 km. During placing, the tender quantity of the OGDL was reached and placing cut off, resulting in a shortfall of 500 metres. The remainder of the section was built using conventional design.

1988 Performance Review on Swedish Design

The MTO Northwestern Region Geotechnical Section conducted a Swedish design performance review on Highway 17 / Kenora By-pass in the summer of 1988. The purpose of the review was to compare the Swedish design pavement structure on the Kenora By-pass versus the conventional granular base and subbase method used by MTO. Several contracts were reviewed to locate sections of highway with similar vertical alignment and soil condition as a comparison. A 1.0 km test section was the basis of the comparison and the cracking in the field was mapped out using 25 m intervals.

HISTORICAL AND PERFORMANCE DATA

There were three test sections involved in this performance review:

- Contract 81-223
  - **Hwy 17** – From the Junction of Hwy 17N and Hwy 17 connection easterly 1.05 km (Swedish design)
- Contract 77-404 and 79-412
  - **Hwy 502** – From 76.8 km South of Hwy 594, northerly 1.0 km
- Contract 80-457 and 81-460
  - **Hwy 596** – From 18.5 km North of Junction Hwy 641 northerly 1.0 km

Tables 4 and 5 below indicate the traffic data and cracking details for each section of the above-mentioned highways:

Table 4 – 1988 Performance Review Traffic Data

Traffic Data	Hwy 17	Hwy 502	Hwy 596
AADT	200	300	550
SADT	360	390	1000
% Commercial	10	20	10
% DHV*	23.5	15	12.9
Year Paved	1983	1979	1981

* DHV – Design Hourly Volume

Table 5 – 1988 Performance Review Cracking Details

Cracking	Hwy 17	Hwy 502	Hwy 596
Transverse (Moderate)	0	218	32
Transverse (Slight)	94	68	30
Partial Transverse (Moderate)	0	174	0
Partial Transverse (Slight)	102	90	0
Centreline Longitudinal (Moderate)	0	313	93
Centreline Longitudinal (Slight)	678	0	2
Midlane & Wheel Track (Moderate)	88	286	0
Meander (Moderate)	0	0	37
Pavement Edge (Moderate)	0	289	0
Pavement Edge (Slight)	89	535	249
Elephant Foot	0	44 ea	4 ea
TOTAL cracks:	**1051**	**1973**	**443**

SUMMARY OF PERFORMANCE REVIEW

According to Table 5 above, Highway 596 has the best performance in terms of the lowest crack counts. Highway 596 was a 1981 contract with a service life of 7 years at the time of the performance review and exhibiting slight to moderate cracking. Highway 17 was a 1981 contract but completed in 1983 resulting a service life of 5 years. Although Highway 17 has the lowest service life among the test sections, the density of the cracking is approximately 50% greater than Highway 596. Highway 502 was a 1979 contract resulting in a service life of 9 years and it experienced approximately 87% more slight to moderate cracking than Highway 17.

ANALYSIS AND CONCLUSIONS

The purpose of the 1988 performance review was to compare the Swedish design to the conventional design. Therefore, the analysis was based on the comparison between the Swedish design (Highway 17) and the conventional designs (Highway 596 and 502). Comparing Highway 17 (Swedish design) to Highway 596, the traffic data indicates a 2.5 times higher volume in Highway 596 and two more years of service life. However, the crack density was in fact 50% more in Highway 17 than Highway 596. Comparing Highway 17 to Highway 502, with four additional years of service life and higher traffic volume, it was reasonable to expect more cracks on Highway 502. Therefore, it is reasonable to have 82% more slight to moderate cracking on Highway 502 than Highway 17.

Northwestern Region concluded that the performance of the Swedish design and the conventional pavement structure indicated that the cracking was not being minimized by the Swedish design methodology.

1999 Justification Report on Highway 17 / Kenora By-Pass

In 1999, a pavement evaluation was conducted under work project WP 51-97-00 to determine and recommend the best rehabilitation strategies for this Highway 17 / Kenora By-pass. The justification report written by the MTO Northwestern Region, recommended a rehabilitation strategy based on the information from this pavement evaluation conducted in 1999.

DETAILED PAVEMENT EVALUATION

The region carried out a detailed evaluation of the pavement performance along the complete Highway 17 / Kenora By-pass. To simplify this study, it was conducted by dividing the By-pass into seven sections with each section having a similar pavement structure. The service life of these pavements sections were between 10 to 12 years at the time of pavement evaluation. Figure 7 below shows the geography location of the 7 sections:

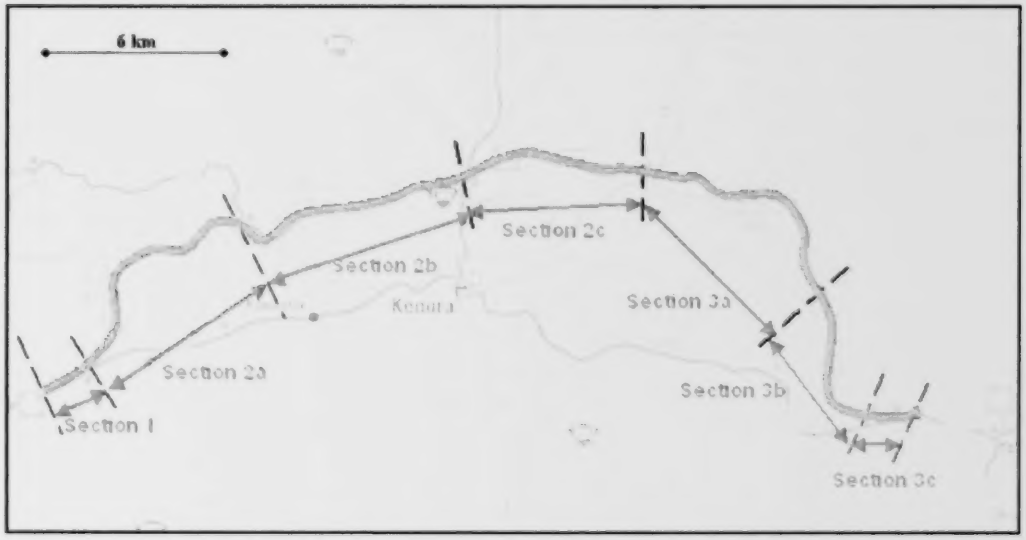

Figure 7 – Highway 17 / Kenora By-Pass Divided into 7 Subsections

Following are the pavement evaluation summaries of the 7 subsections along Highway 17 / Kenora By-pass from the work project WP 51-97-00.

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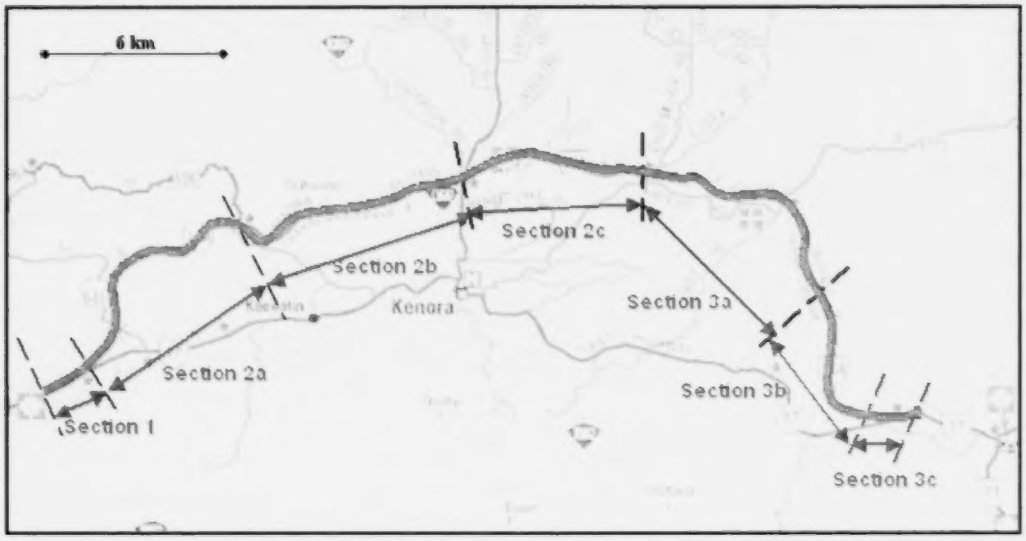

Figure 7 – Highway 17 / Kenora By-Pass Divided into 7 Subsections

Following are the pavement evaluation summaries of the 7 subsections along Highway 17 / Kenora By-pass from the work project WP 51-97-00.

Section 1 – Swedish Design (40mm + 40mm HL-4, 75mm levelling stone, 125mm open drainage stone) located 1.2 km west of west connection, Highway 17/17A easterly to west connection with a length of 1.2 km. This section of highway was last rehabilitated in 1989, resulting in a service life of 10 years at the time of this pavement evaluation review. Following are the pavement distress summary for this Section 1:

- Slight / moderate distortion and meandering cracking
- Midlane multiple cracks
- Slight settlement, longitudinal or crescent cracks at isolated locations
- Alligator and potholes
- Wheel track rutting, possible loss of granular through rockfill

Section 2a - Swedish Design (40mm + 40mm HL-4, 40mm levelling stone, 110mm open drainage stone) located at west connection Highway 17/17A easterly to Highway 596 for a length of 7.1 km. This section of highway was last rehabilitated in 1989, resulting in a service life of 10 years at the time of this performance review. Following are the pavement distress summary for this Section 2a:

- Slight / moderate settlement
- Severe transverse cracks (multiple cracks)
- Segregation, visible moisture
- Very slight to moderate distortion
- Severe edge cracking at isolated areas
- Hot mix patch placed twice or more on pothole 5 m long along centreline
- Crescent crack to centreline
- Wheel track rutting
- Slight / moderate rolling profile from settlement
- Delamination of pavement layers

Section 2b- Swedish Design (40mm + 50mm HL-4, 75mm levelling stone, 125mm open drainage stone) located between Highway 596 easterly to Highway 658 for a length of 7.8 km. This section of highway was last rehabilitated in 1987, resulting in a service life of 12 years at the time of this pavement evaluation review. Following are the pavement distress summary for this Section 2b:

- Ravelling and cracking
- Slight distortion at transverse cracking near centreline
- Moderate to severe settlement with crescent cracking
- Slight to moderate wheel track rutting
- Slight to very slight frost heaving
- Severe longitudinal cracks at isolated locations

Section 2c – Modified Swedish Design (40mm + 50mm HL-4, 75mm levelling stone, 125mm open drainage stone) located between Highway 658 easterly to Highway 659 for a length of 6.2 km. This section of highway was last rehabilitated in 1988, resulting a service life of 11 years at the time of this performance review. Following are the pavement distress summary for this Section 2c:

- Distortion, moderate wheel track rutting with alligator cracks
- Flushing and slight wheel track rutting at isolated locations
- Possible frost heaves
- Moderate settlement at isolated areas
- Severe meandering cracks
- Rolling profile

Section 3a – Conventional Design (40mm + 40mm HL-4, 150mm Granular A, 150mm Granular B Type I) located from Highway 659 easterly to 200 m east of the CPR overhead for a length of 7.0 km. This section of highway was last rehabilitated in 1989, resulting in a service life of 10 years at the time of this performance review. Following are the pavement distress summary for this Section 3a:

- Slight distortion with meandering cracks
- Severe foreslope erosion
- Edge cracking with slight distortion
- Slight to moderate wheel track rutting
- Severe transverse cracks
- Slight settlement

Section 3b - OGDL Design (40mm + 40mm HL-4, 100mm OGDL, 50mm Granular A, 150mm Granular B Type I) located from 200 m east of CPR overhead easterly for a length of 4.0 km. This section of highway was last rehabilitated in 1989, resulting in a service life of 10 years at the time of this pavement performance review. Following are the pavement distress summary for this Section 3b:

- Wheel track rutting and ravelling, moderate
- Severe transverse cracks
- Crescent cracks with slight to moderate distortion
- Numerous hot mix patches
- Shoving - Guide rail moved outwards (almost 1 m)
- Meandering and diagonal cracks

Section 3c - Conventional Design (40mm + 40mm HL-4, 150mm Granular A, 150mm Granular B Type I) located from 4 km east of the CPR overhead to 200 m west of the east junction for a length of 1.2 km. This section of highway was last rehabilitated in 1989, resulting in a service life of 10 years at the time of this pavement performance review.

Following are the pavement distress summary for this Section 3c:

- Moderate settlement
- Severe transverse cracking with slight distortion
- Very slight settlement over culvert

1999 JUSTIFICATION REPORT RECOMMENDATIONS

According to the pavement historical data from the previous contracts, and the pavement evaluation information from work project WP 51-97-00, as well as the existing pavement structure, the justification report recommended a 50 mm overlay to extend the pavement life for another 8 to 10 years. The pavement service life would be exceeded by 2001, however the capital project was postponed to summer 2003. By applying the overlay to extend the life of the pavement, the current Swedish design structure could be sustained and further performance studies of this Swedish design are possible.

2000 Automated Road Analyzer Review

A performance review was conducted in 2000 using the Automated Road Analyzer (ARAN) to measure the roughness and rut depth of the pavement surface, which reflects the condition of the pavement structure.

To simplify this performance review, the By-pass was divided into the same 7 sections as in the previous chapter. In order to show the correlations between the pavement performances and the construction history, the following figure incorporated all the contracts, and the 7 sections altogether for clarity.

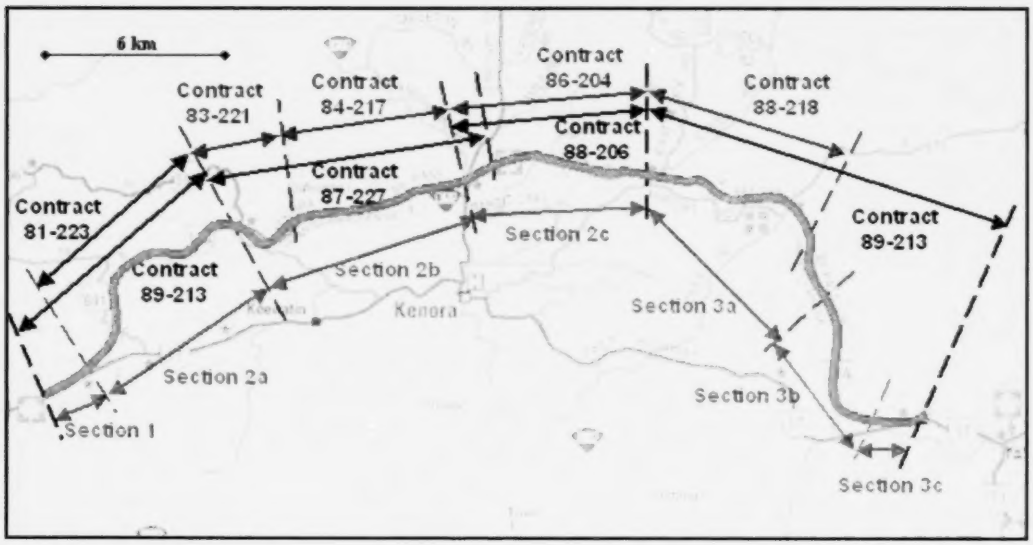

Figure 8 – Highway 17 / Kenora By-pass with Contracts and 7 Subsections

ARAN RUT DEPTH MEASUREMENT

The Automated Road Analyzer (ARAN) is a device used to analyze the pavement condition. One of the measuring properties of the ARAN is to measure the rut depth in the wheel path. Following is the rut depth measurement collected by the ARAN in 2000.

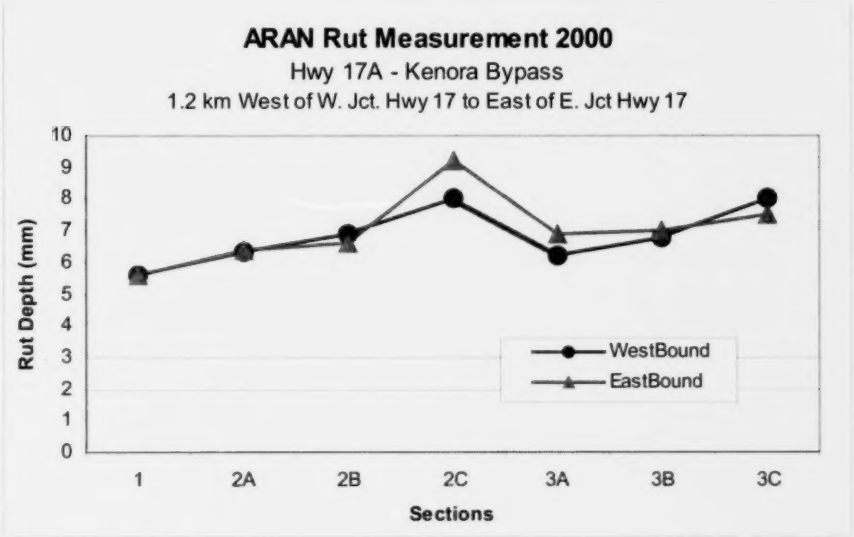

Figure 9 – ARAN Measurement of Average Rut Depth on Highway 17 By-Pass

ARAN ANALYSIS AND CONCLUSIONS

According to the average rut depth measurement in Figure 9, it was found that the highest rutting occurs at Section 2c with an average rutting of 8.6 mm. The remaining sections are relatively uniform with average rut measures ranging from 5.6 to 7.75 mm. Section 2c is one of the Swedish design pavement section constructed under Contracts 86-204 (grading) and 88-206 (paving). Referring to the historical information for these contracts; this section of highway was constructed using the modified Swedish design methodology. Details regarding the failure of the modified Swedish design were discussed in the previous chapter. The modified Swedish design used the same stone size for both levelling and open drainage stone, causing instability of the granular pavement structure; thus encountering difficulty in compaction of the hot mix asphalt. As a result, the rut measure in this section is relatively high compared to other sections in the By-pass.

Overall, by analyzing the rut measurement data, there is no clear distinction between the Swedish design and conventional design, with the exception that the modified Swedish design section experienced the highest rutting.

2001 Falling Weight Deflectometer (FWD) Evaluation

In 2001, Falling Weight Deflectometer (FWD) testing was performed along Highway 17 / Kenora By-pass to evaluate the performance of the pavement structure. FWD testing is a non-destructive method used to measure pavement deflection (mm). Test data can be used to back-calculate the pavement modulus (MPa). This information reveals the quality and strength of the pavement structure.

Table 6 – FWD Testing Summary for Highway 17 By-Pass

Section		Normalized Deflection (mm)	Pavement Modulus (MPa)	Pavement Structure
1	1.2 km W. of West Connection Hwy 17/17A Easterly to West Connection (1.2 km)	0.36	429	40 mm HM asphalt 40 mm HM asphalt 75 mm levelling stone (37.5 mm) 125 mm open drainage stone (75mm)
2a	West Connection Hwy 17/17A Easterly to Hwy 596 (7.1 km)	0.24	638	40 mm HM Asphalt 40 mm HM Asphalt 40 mm levelling stone (37.5 mm) 110 mm open drainage stone (75mm)
2b	Hwy 596 Easterly to Hwy 658 (7.8 km)	0.28	549	40 mm HM Asphalt 50 mm HM Asphalt 75 mm levelling stone (37.5 mm) 125 mm open drainage stone (75mm)
2c	Hwy 658 Easterly to Hwy 659 (6.2 km)	0.29	540	40 mm HM Asphalt 50 mm HM Asphalt 75 mm levelling stone (37.5 mm) 125mm open drainage stone (37.5.mm)
3a	Hwy 659 Easterly to 200 m East of the CPR Overhead (7.0 km)	0.31	493	40 mm HM Asphalt 40 mm HM Asphalt 150 mm Granular A 150 mm Granular B
3b	200 m East of CPR Overhead Easterly for 4.0 km (4.0 km)	0.29	533	40 mm HM Asphalt 40 mm HM Asphalt 100 mm OGDL 50 mm Granular A 150 mm Granular B
3c	4.0 km E. of the CPR Overhead to 200 m W. of the East Junction (1.2 km)	0.33	462	40 mm HM Asphalt 40 mm HM Asphalt 150 mm Granular A 150 mm Granular B

FWD TESTING ANALYSIS

The above table provides a summary of the FWD test results showing the pavement deflection and pavement modulus (MPa), as well as the pavement structure information on the 7 sections.

According to Table 6, Section 2a has the highest pavement modulus (638 MPa); thus having the strongest pavement structure. Section 1 has the lowest pavement modulus (429 MPa); thus having the weakest pavement structure. The pavement moduli for the other sections are relatively similar, ranging between 550 to 450 MPa. The average pavement modulus for the complete By-pass is approximately 520 MPa. The variation in FWD results may be influenced by the subgrade type beneath the pavement structure. The following table summarizes the FWD testing result.

Table 7 – Simplified FWD Results for Highway 17 By-Pass

Section	Pavement Modulus (MPa)	Historical Contracts	Pavement Structure
1	429	89-213	Swedish
2a	638	81-223 & 89-213	Swedish
2b	549	83-221, 84-217 & 87-227	Swedish
2c	540	86-204 & 88-206	Modified Swedish
3a	493	88-218 & 89-213	Conventional
3b	533	89-213	OGDL
3c	462	89-213	Conventional

Section 2a with the highest pavement modulus is one of the Swedish design pavements constructed under Contracts 81-223 and 89-213, contrary the lowest pavement modulus is also one of the Swedish designs (Section 1) constructed under Contract 89-213. In general, it indicates that the conventional design methodology resulted in a weaker pavement structure as the pavement moduli are below average. Section 3b (533 MPa) which was the OGDL design had a pavement modulus above average. It appears that the OGDL provides better drainage, thus, the pavement structure is relatively strong compared to the conventional pavement structure.

Overall, by investigating the FWD testing alone, the conventional pavement structures are generally weaker than the Swedish design structure, likely due to the better stability and drainage system facilitated within the Swedish design.

2002 Crack Mapping Performance Review

The crack mapping exercise was conducted in August 26 and 27, 2002. To simplify the performance measure, the same 7 sections were used to divide up the By-pass (Figure 7). Following are the detailed crack mapping on selected subsections to illustrate the representing pavement condition at the time of survey.

CRACK MAPPING FOR SECTION 1

Section 1 - Swedish Design (40mm + 40mm HL-4, 75mm levelling stone, 125mm open drainage stone) located 1.2 km West of west connection, Highway 17/17A easterly to west connection with a length of 1.2 km. This section of highway was last rehabilitated in 1989, resulting in a service life of 13 years at the time of this crack mapping exercise. This section of By-pass has extensive transverse cracks every 2 to 3 metres. Some cracks stop at centreline to form blocks. Some of the cracks are in the wheel path; however, no wheel track rutting is detected. Visual inspection revealed very slight coarse aggregate loss throughout, and there is an end of load segregation and delamination at station 10+628. Refer to Figure 10 below for the picture showing the delamination at station 10+628.

Figure 10 – Load End Segregation with Delamination at Station 10+628

There are settlements and distortions that were patched on high rock fills. Overall, the pavement was in good condition other than the extensive transverse cracking. Refer to Figure 11 for detailed crack mapping illustration between stations 10+400 to 10+424.

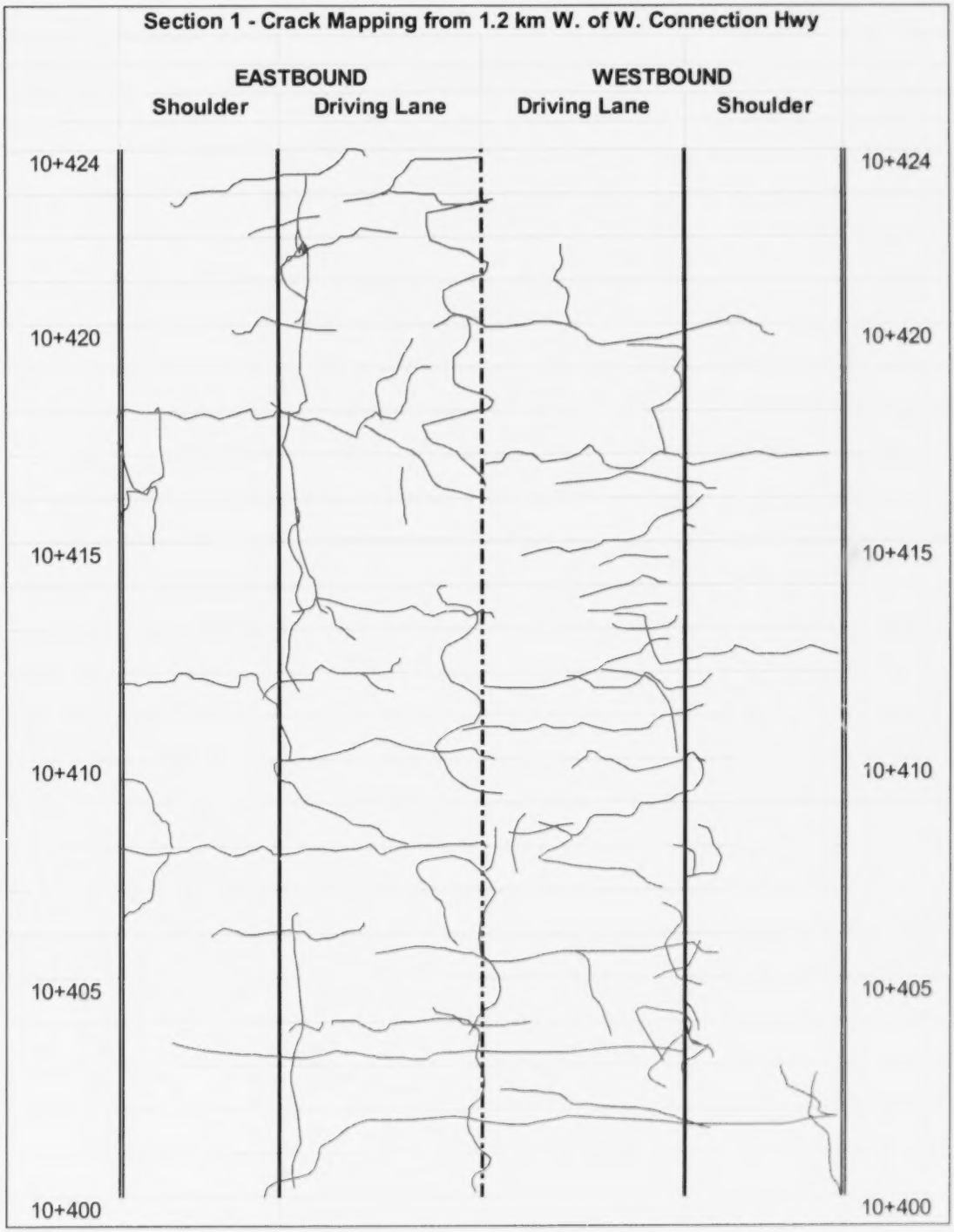

Figure 11 - Crack Mapping of Section 1 (Stations 10+400 to 10+424)

CRACK MAPPING FOR SECTION 2A

Section 2a - Swedish Design (40mm + 40mm HL-4, 40mm levelling stone, 110mm open drainage stone) located at west connection Highway 17/17A easterly to Highway 596 for a length of 7.1 km. This section of highway was last rehabilitated in 1989, resulting in a service life of 13 years at the time of this crack mapping exercise. This section of By-pass has more open cracks with localized spalling and delamination. The high rock fill locations have settlement cracking. Refer to Figure 12 below for the high rock fill settlement.

Figure 12 – High Rock Fill Settlement Cracking in Section 2a

In addition, there was pavement distortion approaching the railway crossing. At localized areas, there were rocks migrating from the base course up to the surface layer causing bumps at stations 14+034 and 16+895 (Figure 13). Refer to Figure 14 & 15 for detailed crack mapping illustrations between stations 15+250 to 15+300.

Figure 13 – Rocks Migrating Up to the Surface Causing Bumps

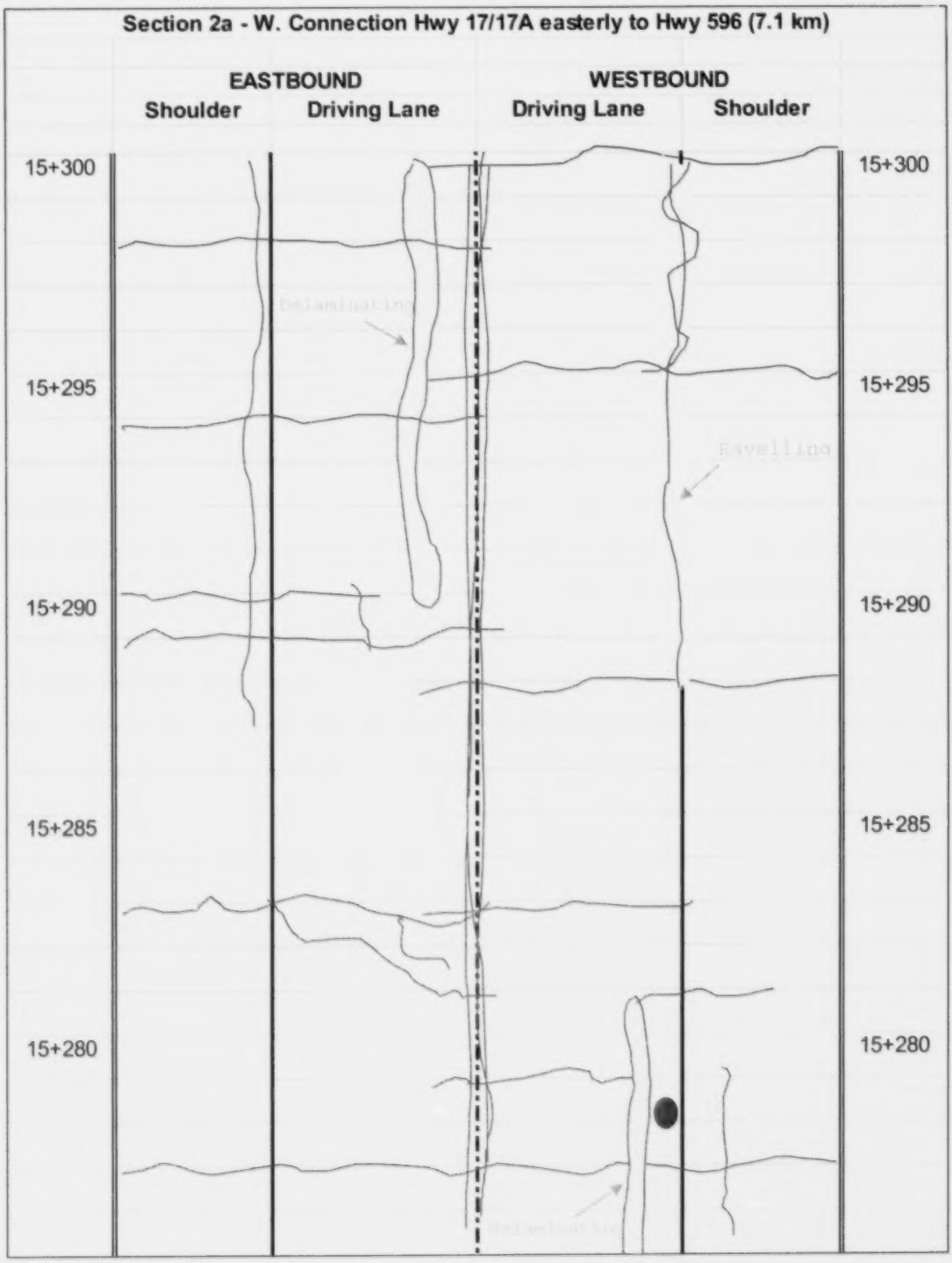

Figure 14 - Crack Mapping of Section 2a (Stations 15+275 to 15+300)

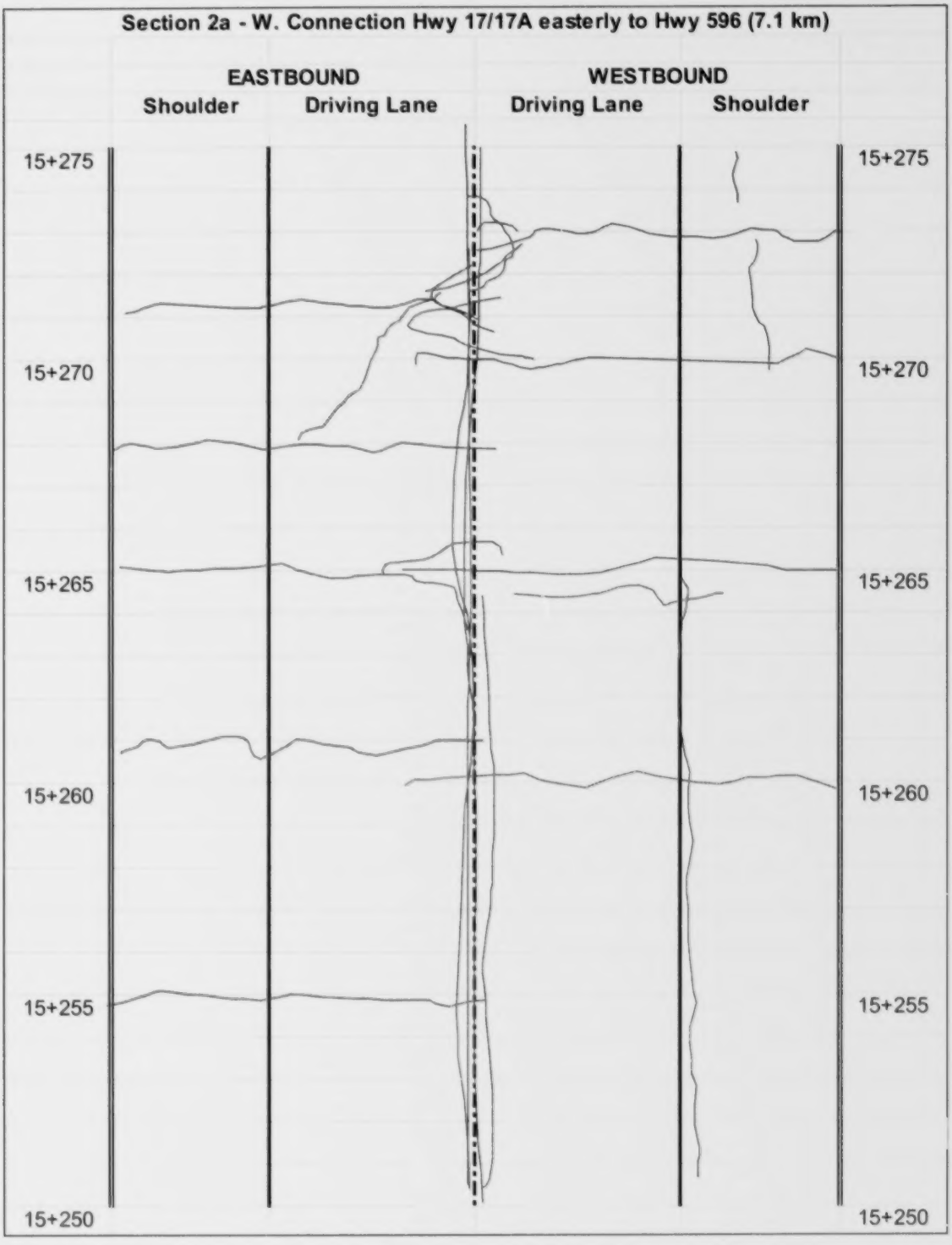

Figure 15 - Crack Mapping of Section 2a (Stations 15+250 to 15+275)

CRACK MAPPING FOR SECTION 2B

Section 2b - Swedish Design (40mm + 50mm HL-4, 75mm levelling stone, 125mm open drainage stone) located between Highway 596 easterly to Highway 658 for a length of 7.8 km. This section of highway was last rehabilitated in 1987, resulting in a service life of 15 years at the time of this pavement evaluation review. This section of By-pass seems to be constructed of smaller sized rock. Figure 16 is a photo taken along the shoulder at station 18+853 indicating smaller rock size was used to construct this section of highway.

Figure 16 –Swedish Design Section 2b Showing 75 mm Levelling Stone

There was less transverse cracking, with cracks every 5 meters and some of the cracks are rout and sealed. At localized areas, there was slight wheel track rutting and ravelling. In general, the pavement was in much better condition compared to the previous sections. Refer to Figures 17 & 18 for detailed crack mapping illustrations between stations 22+948 to 23+004.

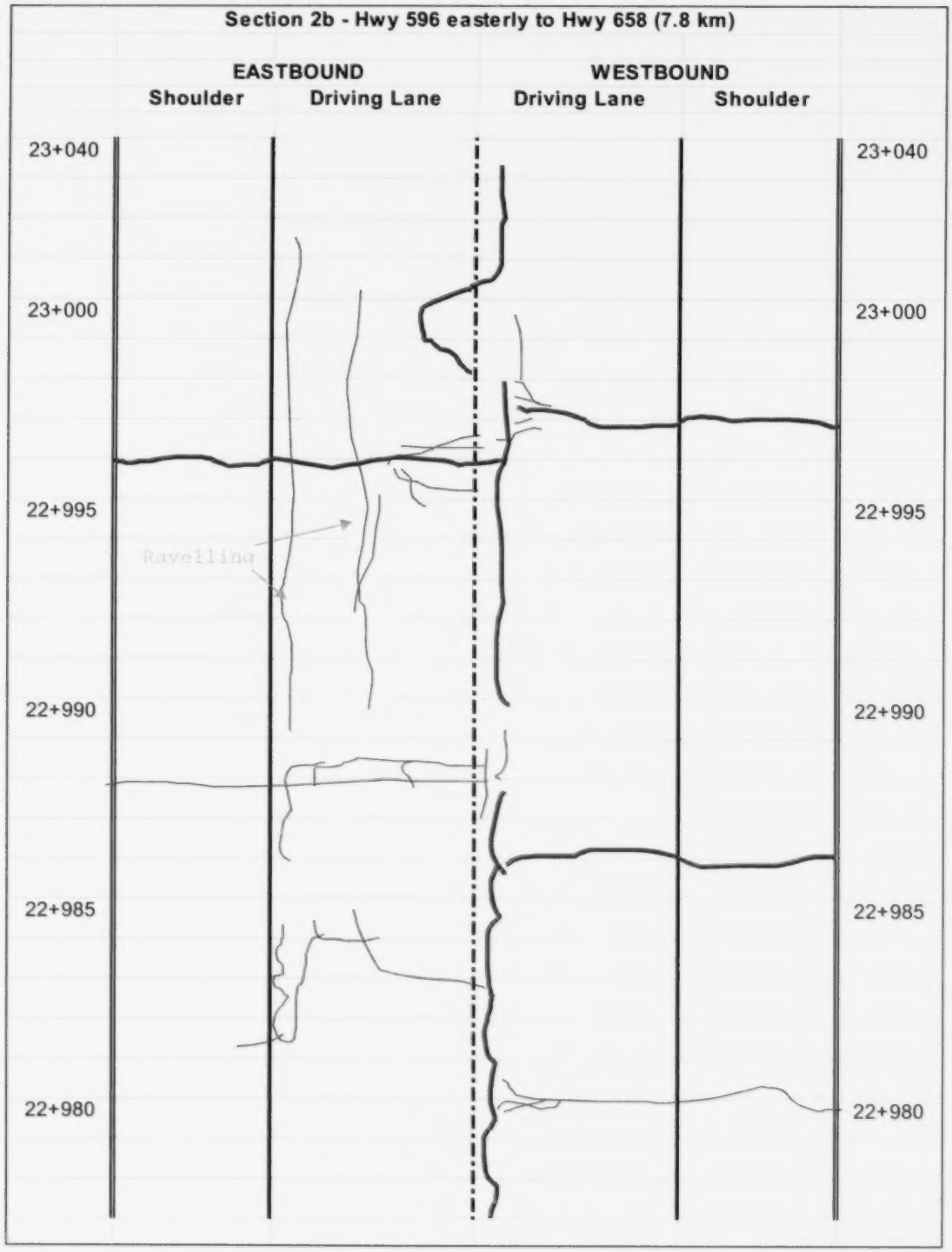

Figure 17 - Crack Mapping of Section 2b (Stations 22+977 to 23+040)

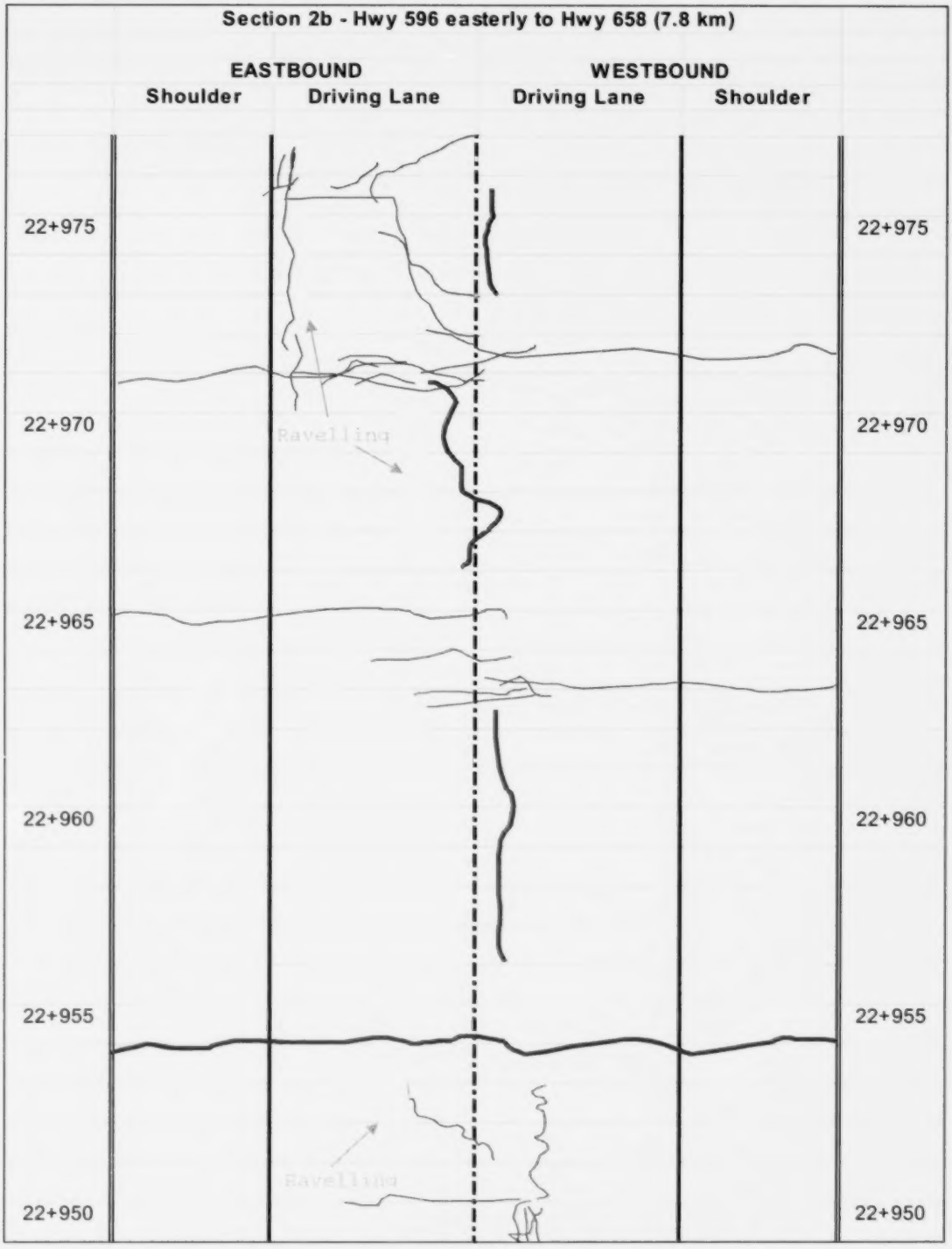

Figure 18 - Crack Mapping of Section 2b (Stations 22+950 to 22+977)

CRACK MAPPING FOR SECTION 2C

Section 2c - Modified Swedish Design (40mm + 50mm HL-4, 75mm levelling stone, 125mm open drainage stone) located between Highway 658 easterly to Highway 659 for a length of 6.2 km. This section of highway was last rehabilitated in 1988, resulting in a service life of 14 years at the time of this crack mapping exercise. This section of By-pass experienced slight flushing, as well as wheel track rutting throughout. The crack and joints are located along the right wheel track on either side, with some transverse cracks routed and sealed. Figure 19 showing the transverse crack has been routed and sealed, and it was in good condition.

Figure 19 – Transverse Crack Routed and Sealed in Good Condition

There is also some multiple alligator cracking along the wheel path, and localized spalling and delamination. Figure 20 showing large rock fill with smaller rock along the shoulder. Typical distresses are detected as per the following graphical illustrations between stations 17+850 to 17+900, Figures 21 & 22.

Figure 20 – Large Rock Fill with Overlying Smaller Crushed Stones Along Shoulder

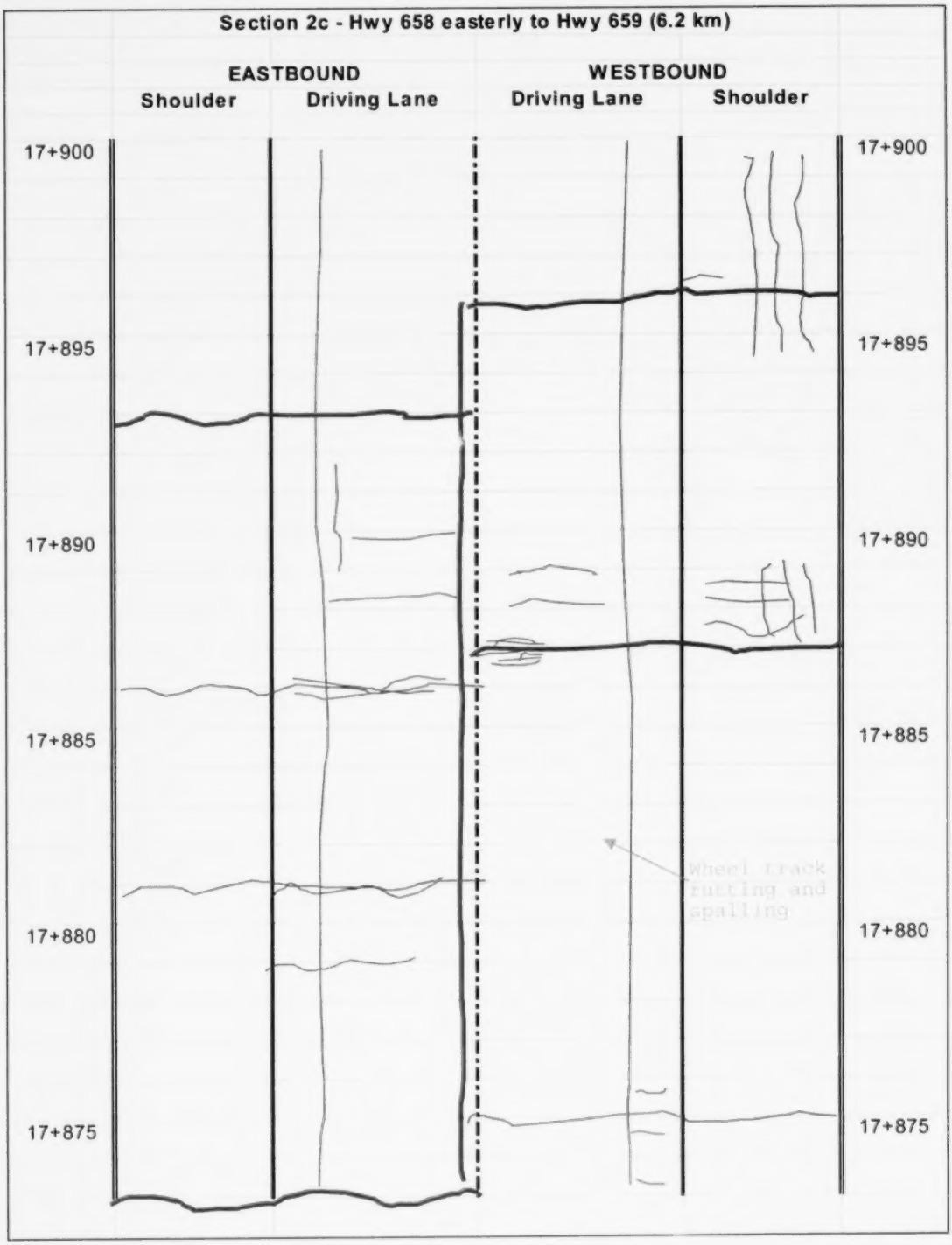

Figure 21 - Crack Mapping of Section 2c (Stations 17+873 to 17+900)

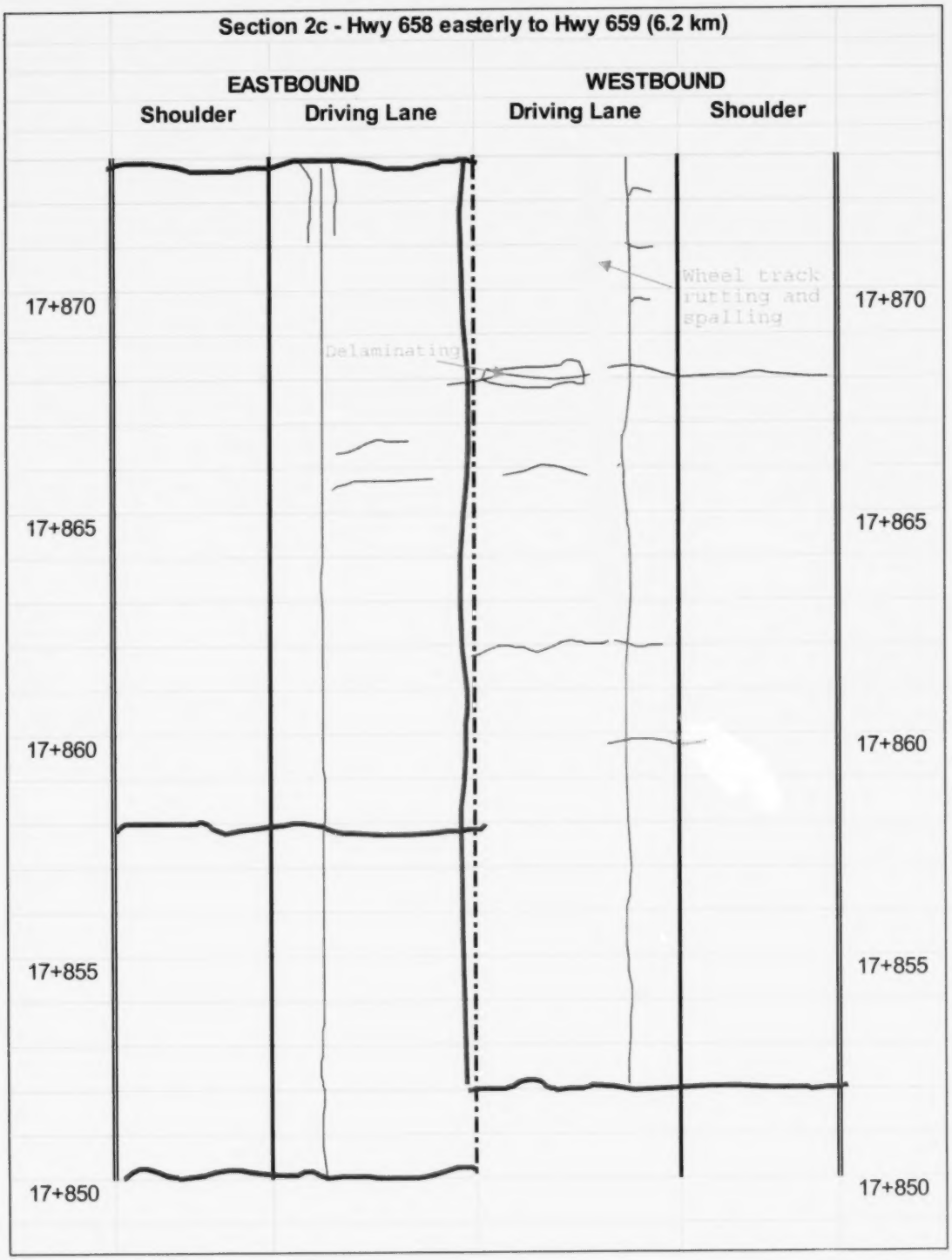

Figure 22 - Crack Mapping of Section 2c (Stations 17+850 to 17+873)

CRACK MAPPING FOR SECTION 3A

Section 3a - Conventional Design (40mm + 40mm HL-4, 150mm Granular A, 150mm Granular B Type I) located from Highway 659 easterly to 200 m east of the CPR overhead for a length of 7.0 km. This section of highway was last rehabilitated in 1989, resulting in a service life of 13 years at the time of this performance review. This is one of the conventional pavement structure sections along this By-pass. Figure 23 shows the Granular A material along the shoulder.

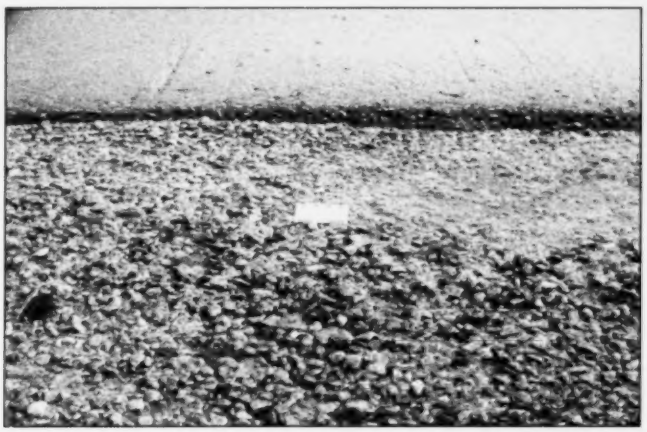

Figure 23 – Granular A Material Along the Shoulder of Section 3a

This section of By-pass has a lot of meander and random cracking, lipped and cupped, and many transverse cracks as well. There were many patches to address the spalling and multiple cracking. Figure 24 shows that the typical meander cracks were cupped or lipped. Refer to Figure 25 for detailed crack mapping illustration between stations 21+850 to 21+875.

Figure 24 – Meander Cracks are Cupped and Lipped

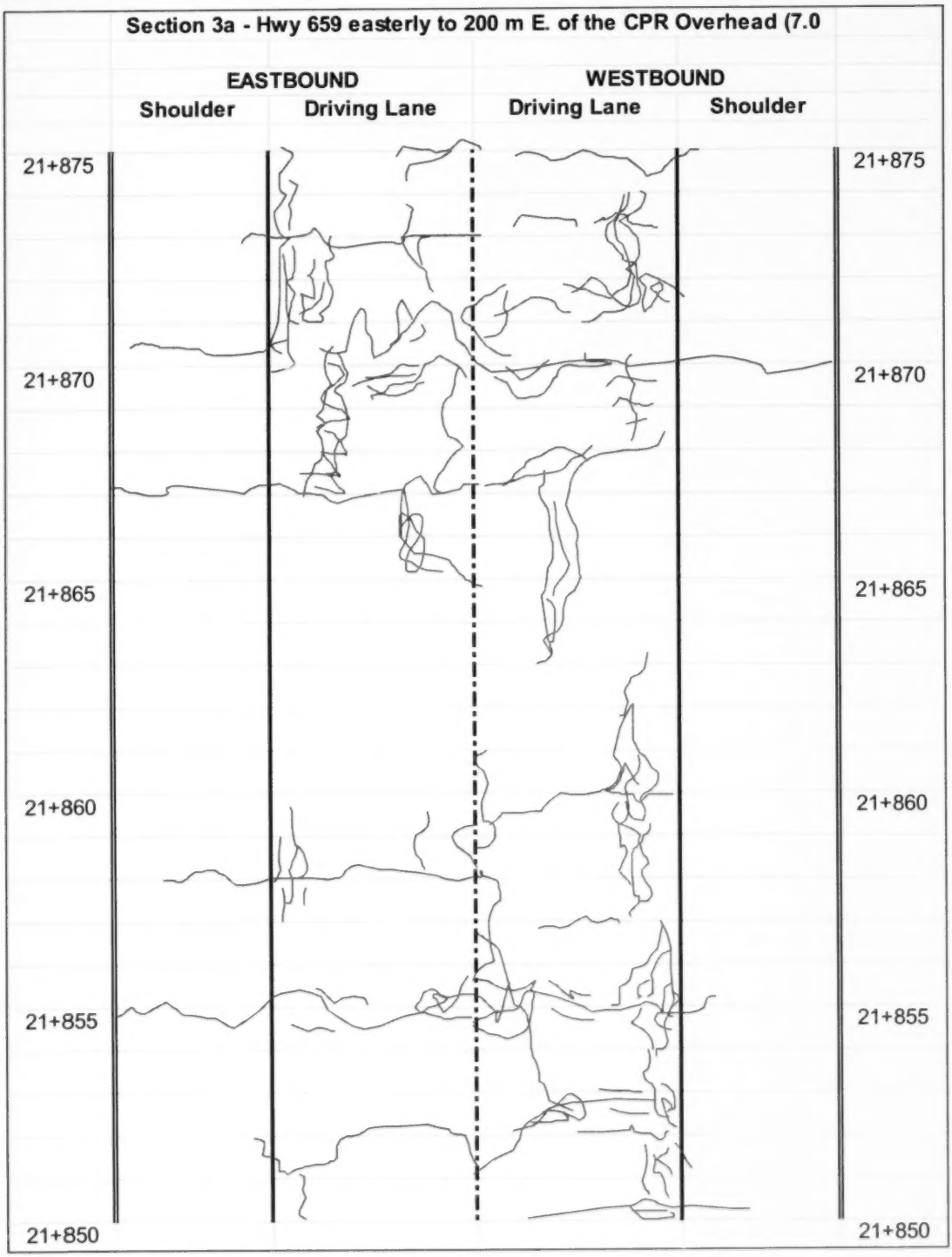

Figure 25 - Crack Mapping of Section 3a (Stations 21+850 to 21+875)

CRACK MAPPING FOR SECTION 3B AND 3C

Section 3b - OGDL Design (40mm + 40mm HL-4, 100mm OGDL, 50mm Granular A, 150mm Granular B Type I) located from 200 m east of CPR overhead easterly for a length of 4.0 km. This section of highway was last rehabilitated in 1989, resulting in a service life of 13 years at the time of this crack mapping exercise. This section combines the visual pavement evaluation for both Sections 3b & 3c. However, the graphical crack mapping illustrations are reflecting the OGDL section (Section 3b) only.

Section 3b with OGDL was the worst performing section due to the rough ride. For Section 3b, there are a lot of transverse cracking with lipping, cupping and spalling. In general, the cracks are much more open compared to other sections. Figure 26 shows the severe transverse cracks were cupped contributing to a rough ride.

Figure 26 – Severe Cupped Transverse Cracking

Section 3c - Conventional Design (40mm + 40mm HL-4, 150mm Granular A, 150mm Granular B Type I) located from 4 km east of the CPR overhead to 200 m west of the east junction for a length of 1.2 km. This section of highway was last rehabilitated in 1989, resulting in a service life of 13 years at the time of this visual evaluation. The frequency of transverse cracking is less and the condition of the cracking is less severe, with an overall better ride. Figure 27 below shows that the condition of the transverse cracking is less severe compared to Section 3b.

Figure 27 – Less Severe Transverse Cracking with Better Ride on Section 3c

Refer to Figures 28 to 31 for detailed crack mapping illustrations for the OGDL Section 3b, between stations 13+500 to 13+550 and 12+000 to 12+052.

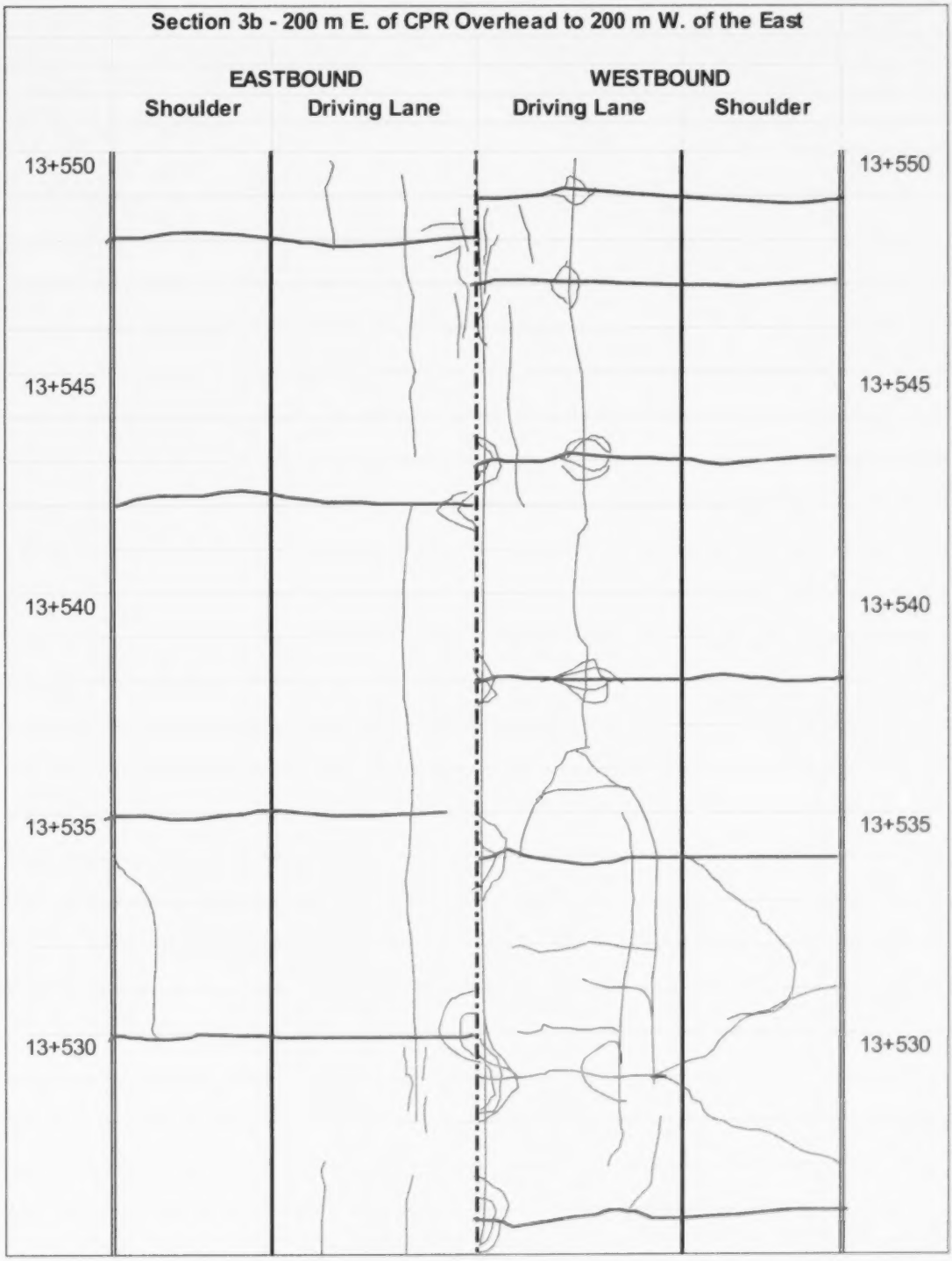

Figure 28 - Crack Mapping of Section 3b (Stations 13+525 to 13+550)

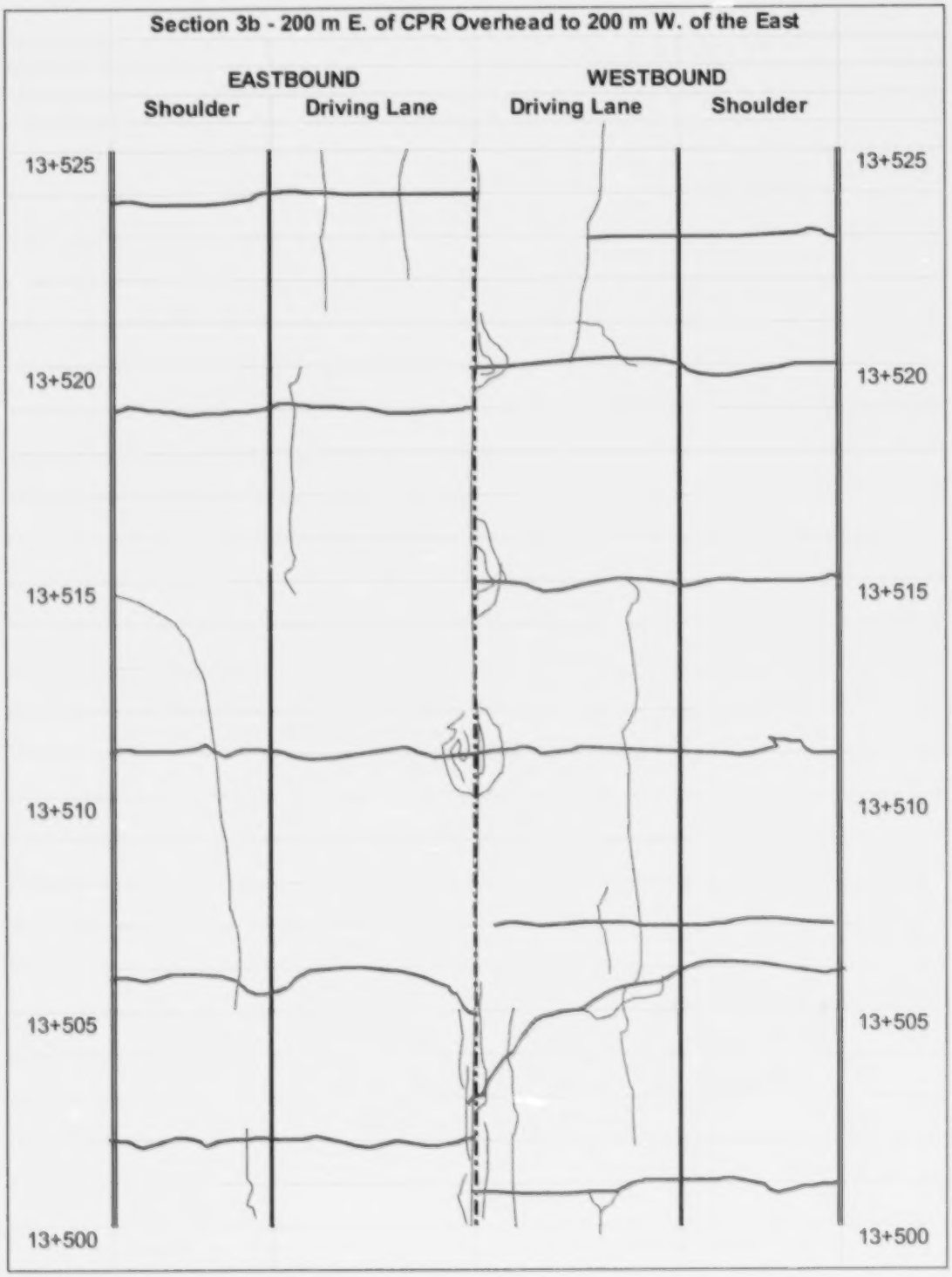

Figure 29 - Crack Mapping of Section 3b (Stations 13+500 to 13+525)

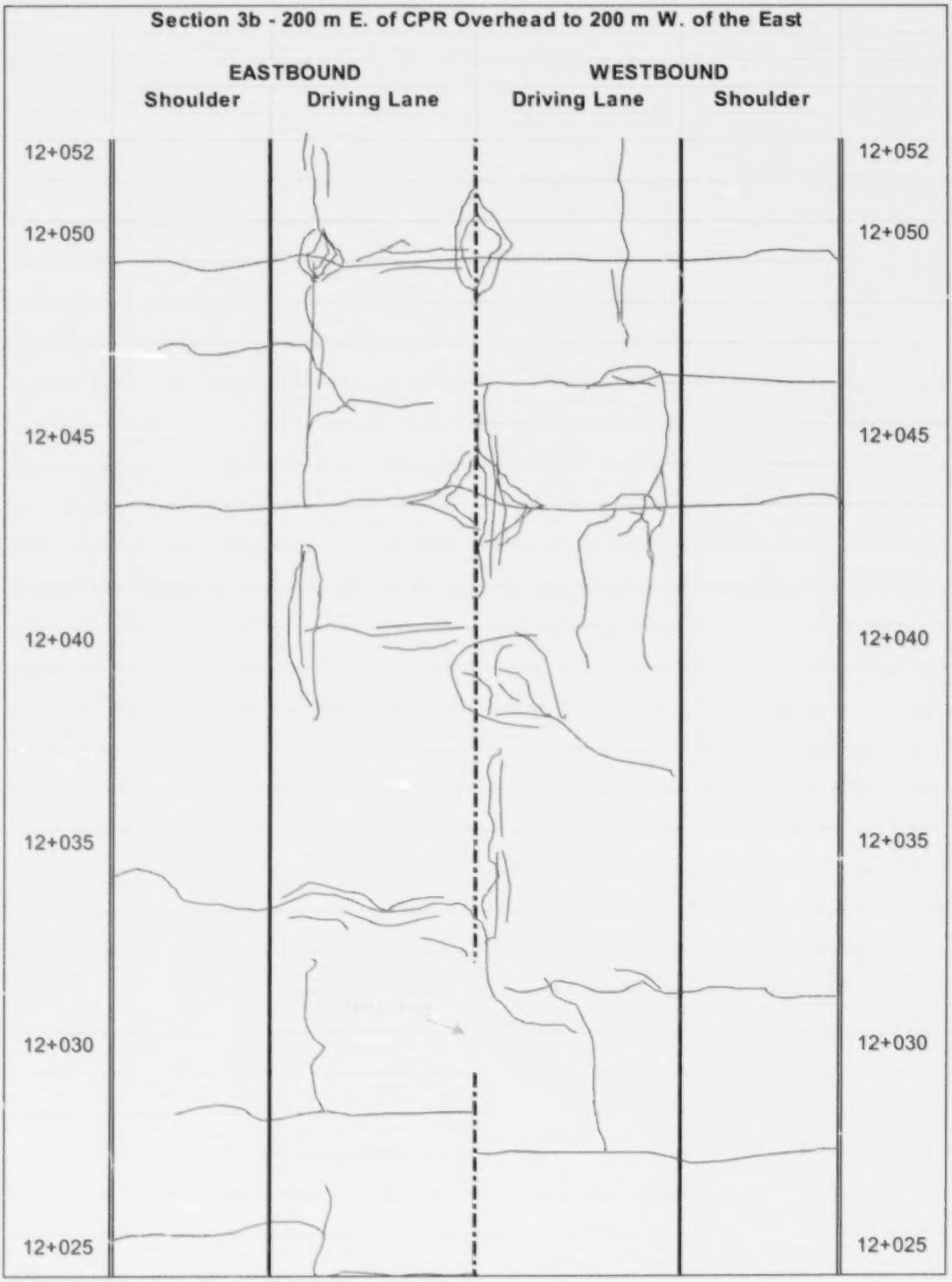

Figure 30 - Crack Mapping of Section 3b (Stations 12+024 to 12+052)

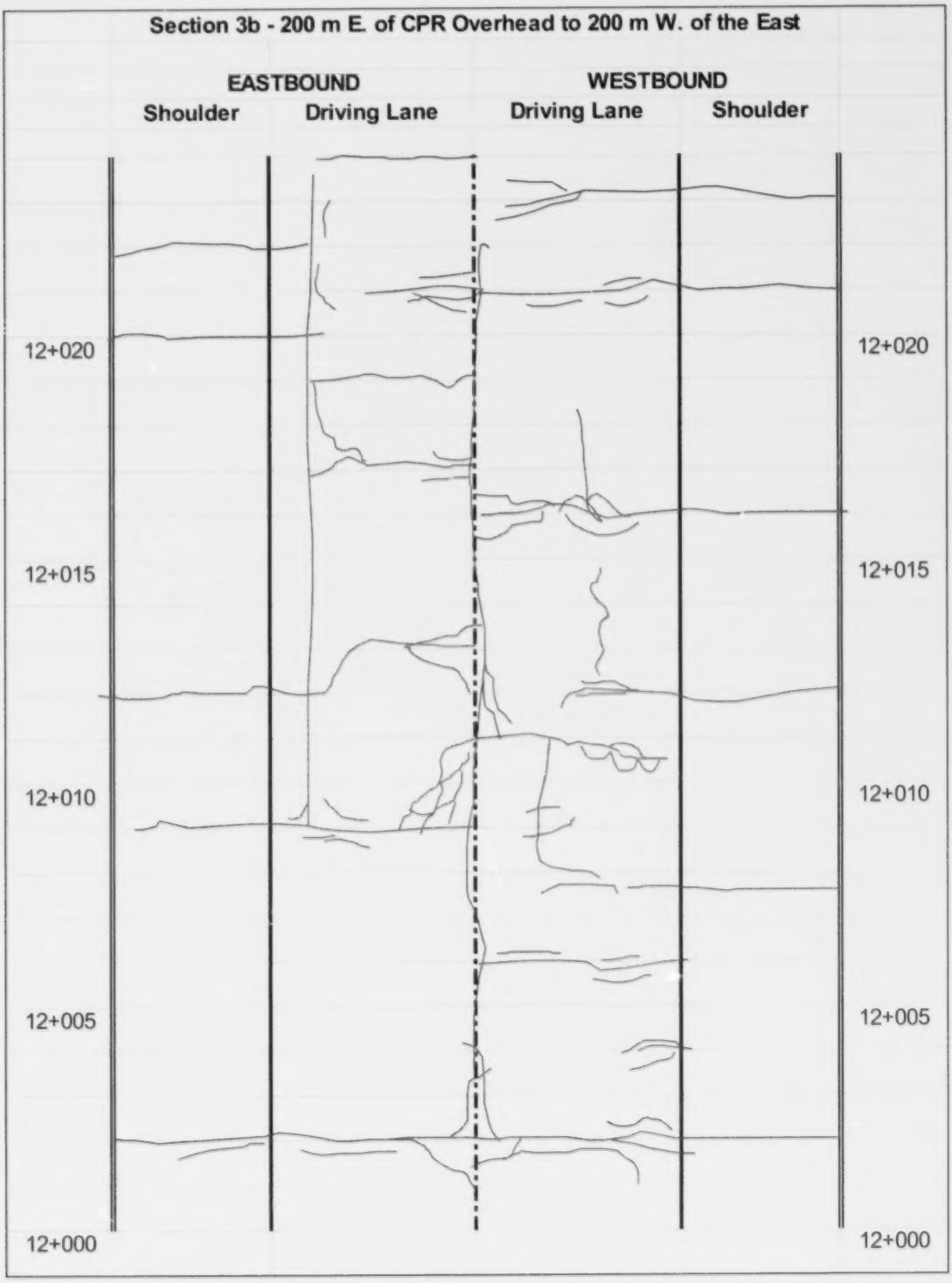

Figure 31 - Crack Mapping of Section 3b (Stations 12+000 to 12+024)

SUMMARY OF CRACK MAPPING PERFORMANCE REVIEW

In general, the crack mapping exercise reveals that the entire Highway 17 / Kenora By-pass is experiencing significant surface distress that required immediate rehabilitation. Considering the average service life of the entire section is 14 years; the condition of the By-pass is performing reasonably well. Below is a summary table comparing the performance of the visual pavement evaluation against the automated FWD pavement modulus that reflects the pavement structural capacity.

Table 8 – Summary of Crack Mapping Performance

Section	FWD Pavement Modulus (MPa)	Visual Pavement Evaluation	Pavement Structure
1	429	No major distress other than many transverse and random cracks	Swedish
2a	638	Localized spalling and delamination with severe cracks	Swedish
2b	549	Slight wheel track rutting and raveling, transverse cracks routed & sealed	Swedish
2c	540	Localized spalling and alligator cracking with transverse cracks routed & sealed	Modified Swedish
3a	493	Meander and random cracking with lipped and cupped	Conventional
3b	533	Very severe transverse cracking with lipped and cupped, and very rough ride	OGDL
3c	462	Transverse cracking is less severe and the ride quality is better than Section 3b	Conventional

Comparing the automated and visual performance review on the data in Table 8, no defining correlation appears to exist between them. According to the crack mapping exercise, the poorest performing section is Section 3b; however the pavement modulus is relatively high compared to other sections. In general, the surface distresses for the Swedish pavement structure and the conventional pavement structure are similar.

In conclusion, the visual pavement performance evaluation does not reflect the actual pavement structural capacity. Even though the pavement section has many surface distresses, the pavement structural capacity is still relatively high.

2003 Hot In-Place Recycling Rehabilitation

The entire Highway 17 / Kenora By-pass was rehabilitated using Hot In-Place Recycling (HIR) in the summer of 2003. Hot In-Place Recycling is a rehabilitation strategy that involves heating and scarification of the pavement surface, in-place processing of the scarified materials with rejuvenators and new hot mix asphalt followed by reprofiling and compaction of the reprocessed materials in one continuous operation. This process is only suitable when the pavement section is structurally sound.

A site visit was conducted on July 16 and 17, 2003 to observe the HIR operation along the By-pass. In general, the HIR operation was moving smoothly with occasional minor charring of the pavement. Figure 32 below shows the minor charring of pavement after heating by the propane fuelled open flame heater.

Figure 32 – Minor Charring of Pavement by Direct Open Flamed Heater

The production rate reported was 2.7 km lane a day with the use of three pre-heaters. It took the contractor approximately 1.5 hours to set up in the morning and one hour to pack up at the end of the day. Discounting the set-up and down time, production was approximately 3.75 m/min. Figures 33 and 34 below show the indirect radiant infrared pre-heater and the direct open flame pre-heater respectively.

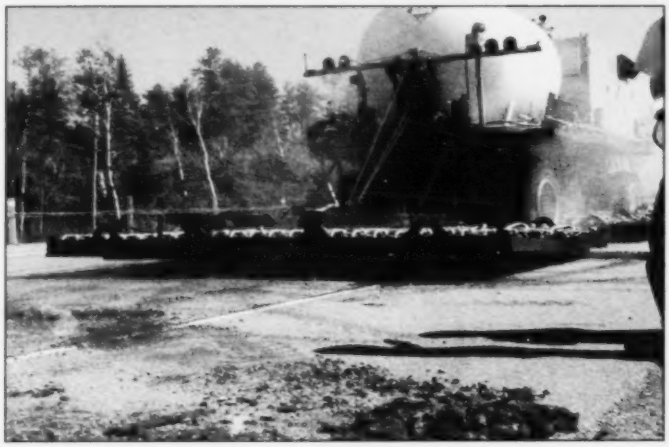

Figure 33 – Infrared HIR Pre-Heater

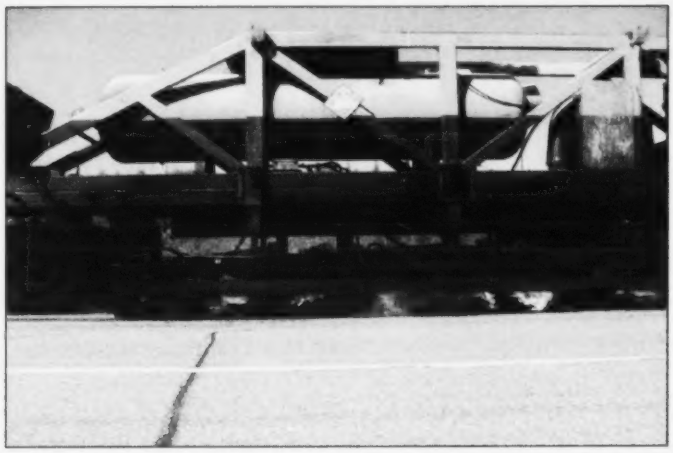

Figure 34 – Open Flame HIR Pre-Heater

The amount of heat/scarified material was electronically monitored using an onboard computer that calculated the quantity of rejuvenator to spray on the HIR material while taking into consideration the speed of the HIR process at that time. Figure 35 shows the onboard computer that monitored the HIR process to ensure the quality of the mix is achieved.

Figure 35 – On-Board Computer To Monitor HIR Material

The material was mixed as it moved through the chamber, then windrowed back to the center of the lane. This equipment was followed by a Material Transfer Vehicle (MTV), Roadtec SB2500B, into which the beneficiating hot mix (admixture) was added (20 to 25%). Figure 36 shows the rejuvenator being added to the heated/scarified material.

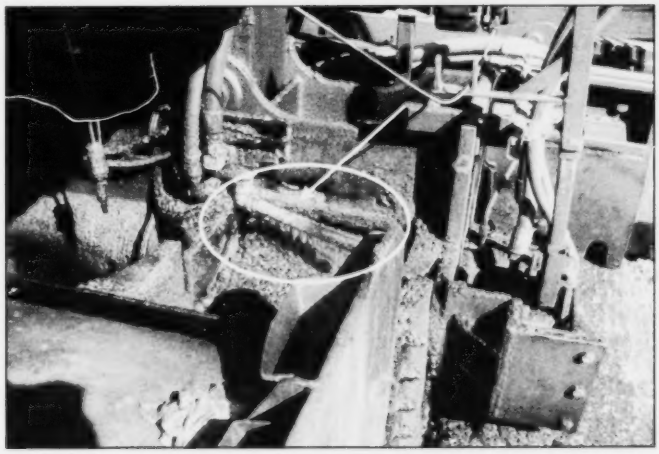

Figure 36 – Rejuvenator Added to the Heated/Scarified Material

Finally, reprofiling and compaction of the HIR mix completed the paving process. Compaction was carried out using a vibratory steel drum roller followed by a pneumatic roller. Figures 37 and 38 below show the placement and compaction process respectively.

Figure 37 – Reprofiling of the HIR Mix

Figure 38 – Vibratory Roller to Compact the HIR Mix

The HIR rehabilitation process along the Highway 17 / Kenora By-pass was completed by the end of summer 2003. Overall, the HIR operation was successful with minor pavement charring caused by the open flame heater. The final mat seems to be smooth with some localized open texture, which might lead to future pavement distresses.

2004 to 2009 ARAN Surveys

The performance of the HIR rehabilitated pavement was evaluated using the ARAN each year from 2004 to 2006. Following the placement of a 50 mm thick Hot Mix Asphalt (Superpave 12.5) overlay in 2007, ARAN data was collected in 2007 to 2009. Because the underlying pavement structure was not disturbed as part of the rehabilitation strategies, the evaluation data is considered to be a valid reflection of the continuing performance of the Swedish design.

The ARAN surveys (conducted on July 9, 2004; July 22, 2005; June 23, 2006; July 13, 2007; July 12, 2008 and July 10, 2009) measured rut depths and calculated International Roughness Index (IRI) along the By-pass. A comparison of the recent ARAN 2004 to 2009 performance review is presented.

ARAN DATA ANALYSIS

The ARAN data was collected separately for westbound and eastbound directions, and the bridge deck sections were eliminated from the data analysis to improve the accuracy of the data set.

In general, the rutting measurement and IRI data results indicate the By-pass is in good condition. The westbound lanes are is not performing as good as the eastbound lanes.

INTERNATIONAL ROUGHNESS INDEX (IRI) MEASUREMENTS

IRI is a standard for pavement roughness measurement. An IRI value of 0 m/km indicates absolute smoothness and an IRI value of 4 m/km and higher represents a rough roadway. Since the scale of IRI is relatively small, the IRI measurement is not very sensitive.

Figure 39 below illustrates the IRI roughness scale [2]. In 2009, the average IRI value for the entire By-pass was1.26 m/km (Table 9), which represents a good newly paved roadway with minimal roughness identified.

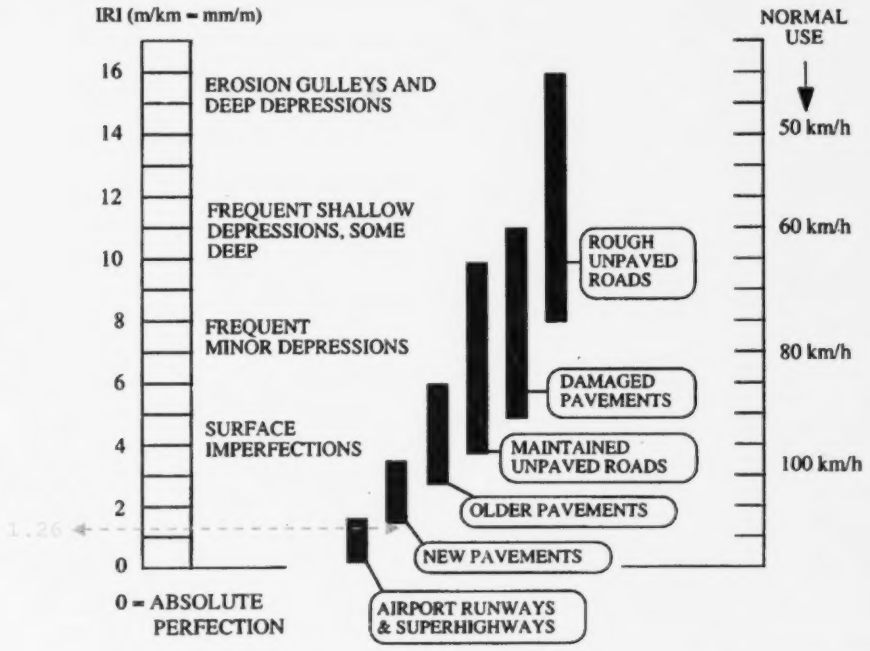

Figure 39 – IRI Roughness Measurement Scale

The average IRI measurements in 2004, 2005 and 2006 were 1.3 m/km, 1.4 m/km and 2.01 m/km respectively which indicated that the By-pass has deteriorated over time since the HIR rehabilitation in 2003. Table 9 below shows the average IRI measures for the seven sections previously delineated in the 1999 Detailed Pavement Evaluation (Figure 7).

Table 9 – 2004 to 2009 IRI Measurement Summary

Section	Pavement Structure	2004 (m/km)	2005 (m/km)	2006 (m/km)	2007 (m/km)	2008 (m/km)	2009 (m/km)
1	Swedish	1.19	1.27	2.35	1.71	1.03	1.42
2a	Swedish	1.34	1.38	2.17	1.47	1.18	1.22
2b	Swedish	1.28	1.44	2.05	1.64	1.14	1.24
2c	Modified Swedish	1.24	1.25	1.53	1.46	1.18	1.24
3a	Conventional	1.18	1.27	1.79	1.41	1.18	1.18
3b	OGDL	1.33	1.48	1.80	1.32	1.11	1.25
3c	Conventional	1.56	1.67	2.38	1.83	1.27	1.24
AVG.		**1.30**	**1.40**	**2.01**	**1.55**	**1.16**	**1.26**

The overall condition of the By-pass in 2004 (one year after the HIR rehabilitation) appears to be fairly uniform among the 7 subsections with only ± 0.37 m/km differences in IRI. Based on IRI measurements from 2004 to 2006, the By-pass experienced an increased rate of deterioration in 2006. Also, the Swedish design sections deteriorated more quickly than the other sections. The IRI measurements for 2007 through 2009 reflect the placement of HMA overlay in 2007, and it shows an immediate improvement in 2007 after the rehabilitation.

Figure 40 below shows the average IRI measurement for the 7 sections from 2004 to 2006.

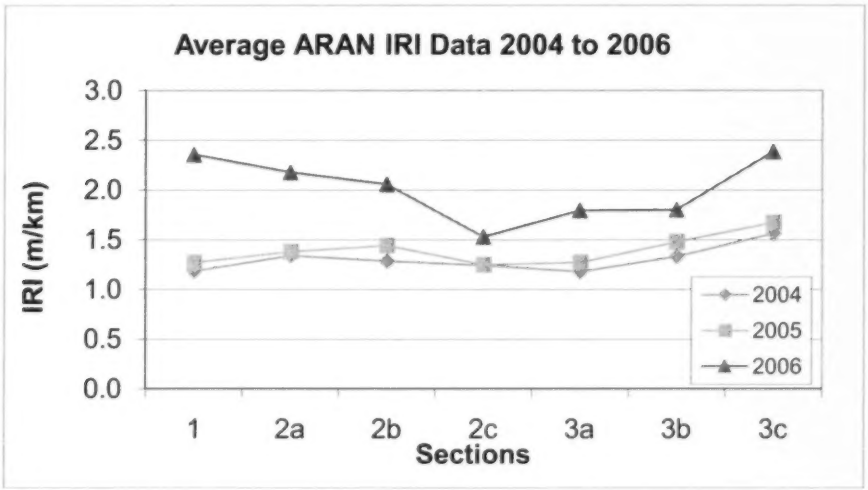

Figure 40 – ARAN 2004 to 2006 Average IRI Roughness Measurement

According to Figure 40, the best performing section based on IRI measure is 2c, which is the modified Swedish design pavement structure. Conversely, Section 3c, a conventional pavement structure, performed the poorest.

The IRI measurement for the complete By-pass after the HMA overlay has improved since 2007. Figure 41 below shows the average IRI measurement for the seven sections from 2007 to 2009.

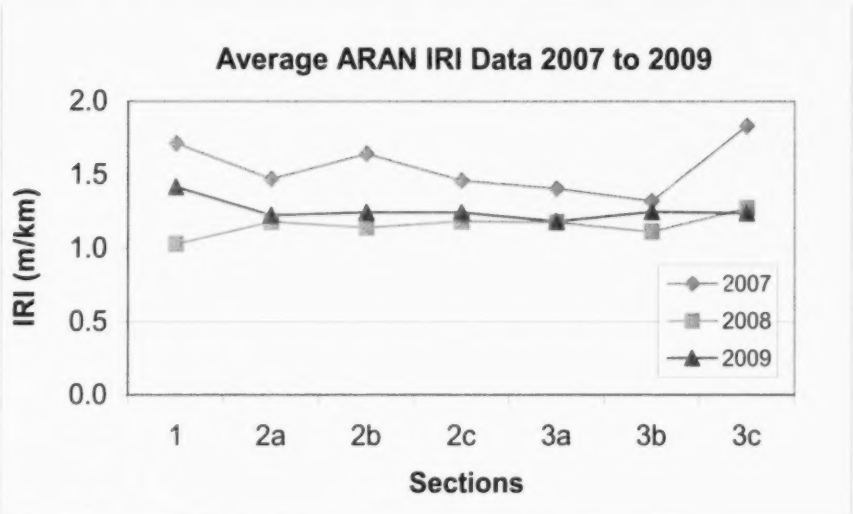

Figure 41 – ARAN 2007 to 2009 Average IRI Roughness Measurement

According to Figure 41, the overall performance of all seven sections is fairly uniform. But interesting to note the IRI measures in 2007 is not as good as 2008 and 2009. The deviation of the IRI measures may be caused by the erroneous initial readings in 2007, resulting in an overall decreased IRI measures in 2008 and 2009.

RUT DEPTH MEASUREMENT

Rut depth measurement is another indicator for pavement performance. The smaller rut depth measures means the pavement is in better condition. However, the rut depth measurement by ARAN only has an accuracy of ± 2 mm, so the data presented here is for reference information only.

Table 10 is the summary of the average rut depth of the 7 sections from 2004 to 2009.

Table 10 – 2004 to 2009 Rut Measurement Summary

Section	Pavement Structure	2004 (mm)	2005 (mm)	2006 (mm)	2007 (mm)	2008 (mm)	2009 (mm)
1	Swedish	3.8	2.5	2.2	3.5	2.4	2.1
2a	Swedish	3.2	2.5	2.1	3.3	2.6	2.4
2b	Swedish	3.0	3.0	2.3	3.4	2.7	2.6
2c	Modified Swedish	2.7	2.5	2.0	3.1	2.9	2.6
3a	Conventional	3.3	2.8	2.0	3.1	2.7	2.5
3b	OGDL	4.0	3.0	2.6	3.1	2.4	2.7
3c	Conventional	4.4	2.9	3.0	3.4	2.5	2.2
AVG.		**3.5**	**2.7**	**2.3**	**3.3**	**2.6**	**2.4**

According to the above table, the average rutting in 2004, 2005 and 2006 are 3.5 mm, 2.7 mm and 2.3 mm respectively. It is interesting to note the average rut measurement of the By-pass actually improves overtime since the HIR rehabilitation in 2003. The rut measurements seem to contradict the IRI measurements. The deviation of the rut depth may be caused by the secondary traffic compaction after the HIR in 2003, which leads to an overall decreased rut depth measurement in 2005 and 2006.

Similarly, the average rutting in 2007, 2008 and 2009 are 3.3 mm, 2.6 mm and 2.4 mm respectively. The average rut measurement of the By-pass has improved since the last HMA overlay rehabilitation in 2007. Again, the deviation of the rut depth may be caused by the secondary traffic compaction after the overlay in 2007, resulting in an overall decreased rut depth measurement in 2008 and 2009.

Figure 42 and 43 below show the average rut depth measurement of the 7 sections from 2004 to 2006 and 2007 to 2008 respectively. Overall, the rut measurements for the By-pass are all in the slight rutting range.

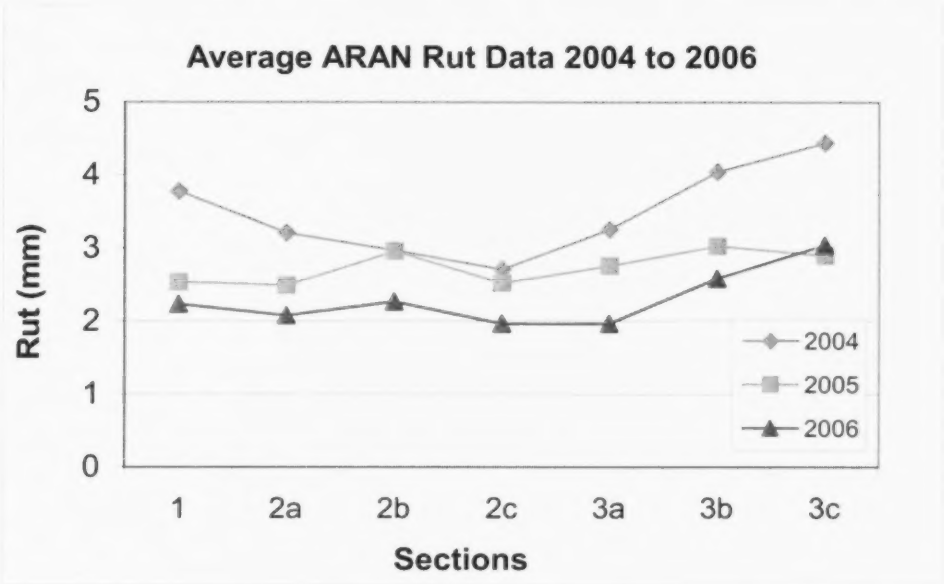

Figure 42 – ARAN 2004 to 2006 Average Rut Measurement

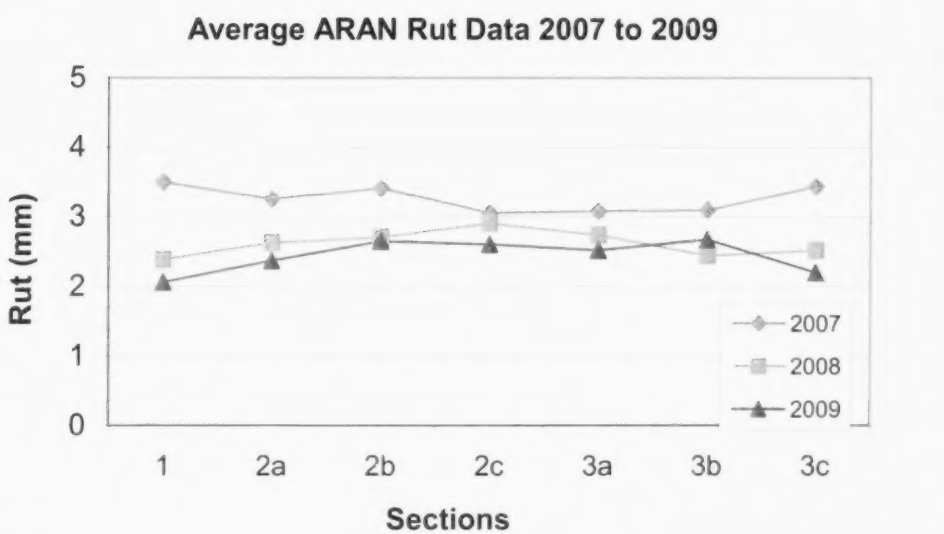

Figure 43 – ARAN 2007 to 2009 Average Rut Measurement

Figure 44 shows the eastbound and westbound rut measurements for the 7 sections. It is interesting to note the rutting measurement for westbound lanes are slightly worse than the eastbound lanes. The average rutting for the eastbound lane is 2.6 mm, whereas the westbound lane is 3.0 mm. The overall rut measurements among the 7 sections are fairly similar for the eastbound and westbound lane, with the westbound lane performing a little worse than the eastbound.

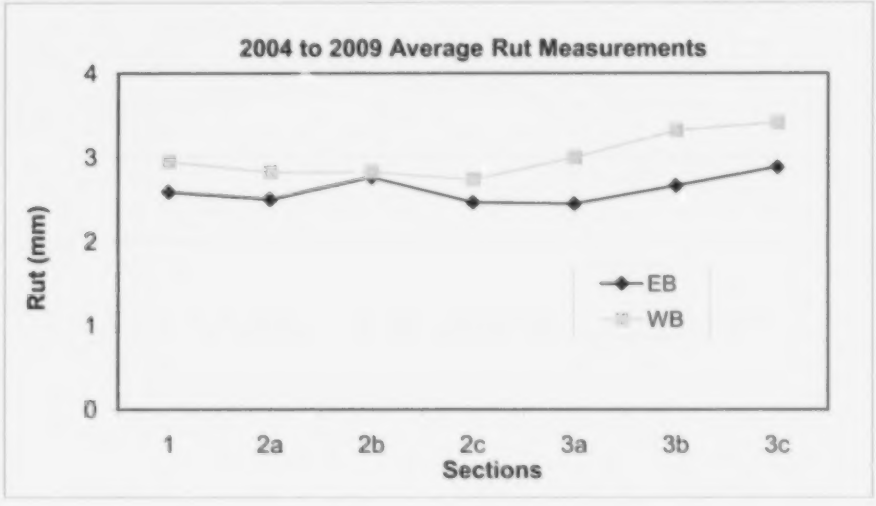

Figure 44 – ARAN 2004 to 2009 Rut Measurement for Eastbound and Westbound Lanes

SUMMARY OF ANALYSIS

In general, the ARAN 2004 to 2005 rut and IRI data indicates the By-pass was in good condition after it has been HIR rehabilitated in 2003. However, the cracks reflected through in less than 6 months after HIR rehabilitation.

In 2006, the ARAN data indicated the By-pass rapidly deteriorated and the average IRI measure indicated an increase of approximately 45% between 2005 and 2006. This is mainly due to the insufficient pavement structure to support the current traffic condition. Therefore, the By-pass was scheduled to apply hot mix overlay in summer 2007 to strengthen the pavement structure. Since then, the ARAN data in 2008 and 2009 indicated the By-pass is performing well with relatively uniform performance overtime among the 7 sections.

In 2004 to 2006 ARAN data, the Swedish design and the conventional pavement design are performing similarly with the modified Swedish design section (Section 2c) performing slightly better in terms of both rutting and IRI measures. However, after the By-pass is rehabilitated with 50 mm HMA overlay, the 2007 to 2009 ARAN results show that all 7 pavement sections are performing similarly. This is because the additional HMA layer has improved the overall performance of the By-pass. Since the 7 sections have different underlying pavement structures, it is expected the pavement performance among the 7 sections will show differential performance over time.

Conclusions

The Highway 17 / Kenora By-pass was the first and only ministry experience using the Swedish design methodology. The concept of this design was to establish a better pavement structure to improve the drainage. However, the Kenora By-pass constructed using the Swedish design experienced numerous construction difficulties throughout. The effectiveness of this design was evaluated by monitoring the pavement performance over time.

Based on the 1988 performance review to compare the conventional and Swedish design, cracking was not minimized by the Swedish design methodology. The ARAN rut depth measurement in 2000 reveals the highest rut depth in the modified Swedish design contract. Conversely, the 2001 FWD testing performance review indicated the Swedish design pavement had an overall higher pavement modulus (MPa) which means it is structurally stronger. The crack mapping in 2002 indicated the pavement surface distresses were similar for the Swedish design and conventional design, with the exception of the OGDL section (Section 3b) which has a very rough ride due to cupping of the transverse cracks. Overall, these assessments suggested that the Swedish design is structurally stronger, likely due to its better drainage characteristics and higher stability from aggregate interlock.

The By-pass was first rehabilitated using HIR in 2003. The ARAN 2004 to 2006 IRI and rut depth measurements indicate that the performance of the Swedish design and the conventional design are comparable, with the modified Swedish design section (Section 2c) performing slightly better in terms of both rutting and IRI measures. The By-pass was rehabilitated once again in 2007 with a 50 mm HMA overlay of Superpave 12.5 and the ARAN results from 2007 to 2009 show that all 7 pavement sections are performing similarly. The additional HMA layer has strengthened the overall pavement structure of the By-pass.

The By-pass has been in service for over 20 years and has an acceptable performance. Although the Swedish design had constructability issues, where placement of hot mix asphalt above the coarse drainage and levelling stone created an unstable surface structure prone to rutting, settlement and distortion; the long term performance of the Swedish design pavement structure performance is comparable to the conventional design based on the visual and automated pavement measurements and evaluations to-date.

Recommendations

The recent ARAN data suggest that the pavement performance of the Swedish design and conventional design is comparable. Based on the evaluation of FWD data, the Swedish design provides a stronger pavement structure and with better drainage. However, the initial stability of the base material resulted in constructability issues affecting the surface performance. Consequently, the overall performance of the Swedish Design structure is disappointing.

Prior to pursuing further Swedish pavement design contracts, additional considerations should be given to:

- Specifying more fines in the stone gradation for better compaction
- Place sand/granular running pad for construction traffic above the levelling stone to avoid damage to the pavement structure and easier for hot mix binder placement
- Do not use Swedish design for high traffic volume sections (i.e., intersections)
- Eliminate the modified Swedish design methodology where the same gradation is used for both levelling and drainage stone
- Use end dumping & levelling with grader instead of spreader box
- Examine life cycle costs of Swedish designs since it has a higher initial cost

Unless the constructability issue can be resolved, it is not cost effective to build Swedish Design pavement structures in Ontario in hopes of achieving better drainage and improved performance.

Acknowledgement

The authors wish to acknowledge the assistance and dedicated work of the staff from Northwestern Region. In particular, the efforts of Earl Warren, Dan Schram, Glen Barnard, Audrey Watterson from Contract Office, and Al Brown from Geotechnical Section are gratefully acknowledged.

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